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SECOND ANNUAL DINNER OF THE MEMBERS OF THE INSTITUTE

THE JOURNAL

OF THE

INSTITUTE OF METALS

VOLUME V

EDITED BY

G. SHAW SCOTT, M.Sc.

SECRETARY

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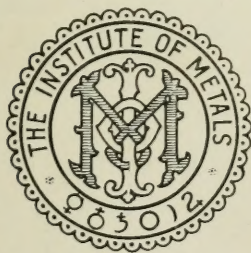
THE INSTITUTE OF METALS

OFFICERS, 1911

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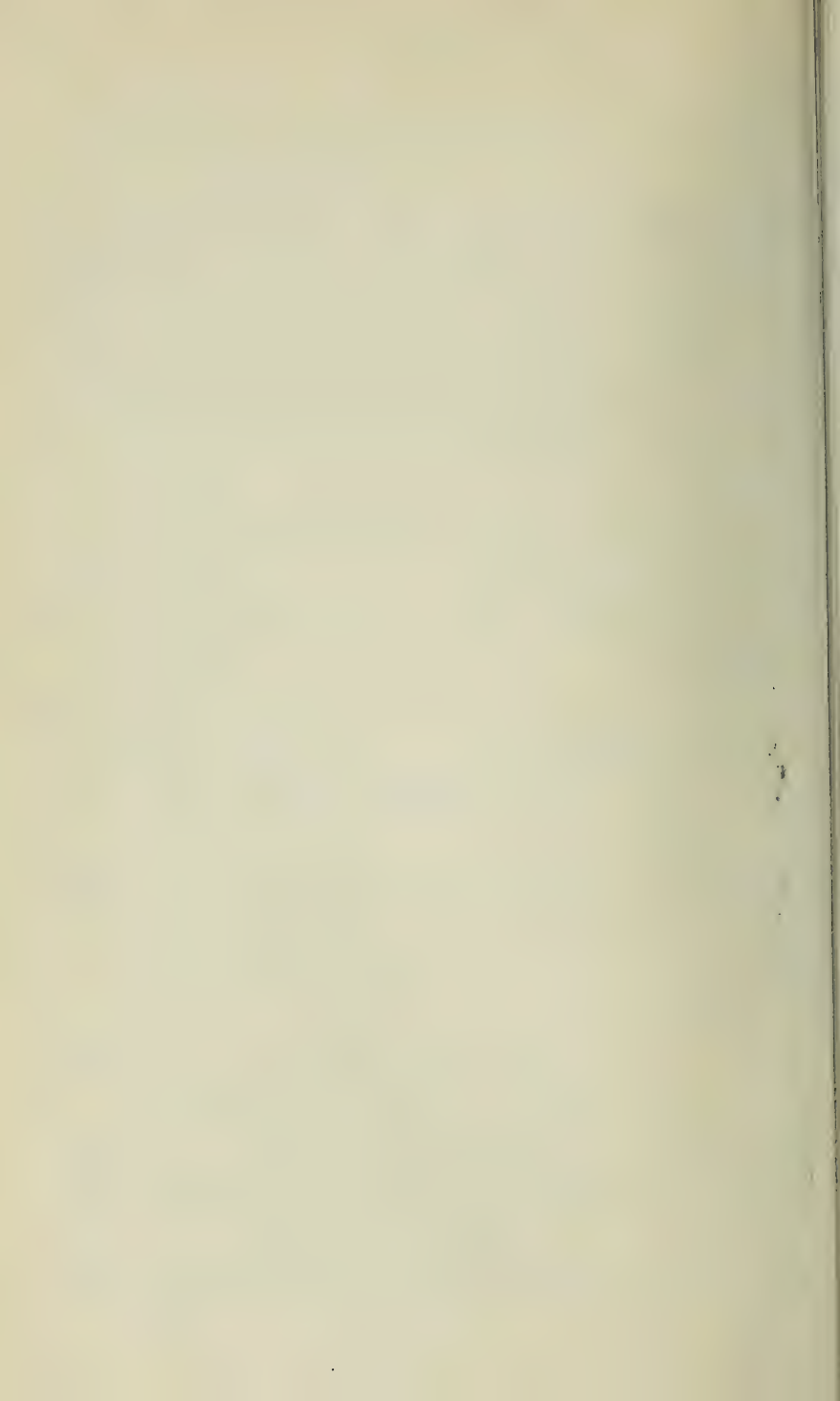
THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the Institute of Metals was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Wednesday, January 18, 1911, Sir Gerard A. Muntz, Bart., President, occupying the chair.

The SECRETARY read the Minutes of the previous meeting, held on Tuesday, October 11, 1910, which were found to be a correct record, and were signed by the Chairman.

The SECRETARY then read the following Report of Council upon the Proceedings of the Institute during the year 1910 :—

REPORT OF COUNCIL.

In presenting to the members their Annual Report of the Institute of Metals the Council have pleasure in stating that the year 1910 marked a period of material development in the activities of the Institute and a steady growth in the membership.

THE ROLL OF THE INSTITUTE.

The number of members on the roll of the Institute on December 31, 1910, was as follows :—

Fellow	1
Honorary Members	3
*Original Members	438
Ordinary Members	86
Student Members	23
Total	551

* Original Members are those who joined prior to July 1, 1909.

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The following table shows the development that has taken place since the Institute was founded in 1908 :—

	Dec. 31, 1908.	Dec. 31, 1909.	Dec. 31, 1910.
Fellows	...	...	1
Honorary Members	...	1	3
Original Members	350	479	438
Ordinary Members . . .	...	13	86
Student Members	5	12	23
Total	355	505	551

During the year the Council appointed the first Fellow of the Institute in the person of Sir William H. White, K.C.B., Sc.D., LL.D., F.R.S., the value of whose services to the Institute in his capacity as President during the years 1908–10 must always be most highly appreciated by members of this Institute.

Two new Honorary Members were appointed by the Council during the past year, these being Dr. R. T. Glazebrook, D.Sc., F.R.S., and Sir Andrew Noble, Bart., K.C.B.

The Council regret to have to record the death of Mr. J. D. Bonner, a Vice-President of the Institute, which occurred on August 13.

INCORPORATION.

For many months the Council was engaged in the necessary legal formalities in connection with the incorporation of the Institute. On September 10 the Certificate of Incorporation of the Institute was obtained, and the Institute thereby became a body possessing all the advantages of a Limited Liability Company, yet, by special license from the Board of Trade, it was exempt from including in its title the word " Limited."

MEETINGS.

During 1910 four meetings were held. The Annual General Meeting took place in London on January 18 and 19, the retiring President (Sir William H. White) occupying the Chair prior to the declaration of the result of the ballot for the Council for 1910, after which Sir Gerard A. Muntz, Bart., assumed office as President, and

delivered his Presidential Address. The following papers were read and discussed :—

1. " On the Use of Carbonaceous Filters in the Smelting of Zinc, as Employed in the Hopkins Fumeless Zinc Process." By C. O. BANNISTER (London).
2. " On the Properties and Constitution of Copper Arsenic Alloys." By G. D. BENGOUGH (Liverpool).
3. " On the Failure in Practice of Non-Ferrous Metals and Alloys, with particular reference to Brass Loco-Tubes." By T. VAUGHAN HUGHES (Birmingham).
4. " On a Contribution to the Study of Phosphor Bronze." By O. F. HUDSON (Birmingham) and E. F. LAW (London).
5. " On Notes on a Suggested Record of Analyses." By C. A. KLEIN (London).
6. " On the Analysis of Aluminium and its Alloys." By Dr. RICHARD SELIGMAN (London) and F. J. WILLOTT (Wallsend-on-Tyne).
7. " On the Assay of Industrial Gold Alloys." By ERNEST A. A. SMITH (Sheffield).

An important innovation was the First May Lecture. This was delivered on May 24 by Professor W. Gowland, F.R.S., on " The Art of Working Metals in Japan."

The Autumn Meeting was held at Glasgow on September 21, 22, and 23. Very complete arrangements were made by an influential Local Reception Committee, of which Professor A. Barr was Chairman, and the meeting was most successful. The following papers were read and discussed on that occasion :—

1. " On the Heat-treatment of Brass—Experiments on 70 : 30 Alloy." By G. D. BENGOUGH (Liverpool) and O. F. HUDSON (Birmingham).
2. " On Some Common Defects occurring in Alloys." By Dr. CECIL H. DESCH (Glasgow).
3. " On Shrinkage of the Antimony-Lead Alloys and of the Aluminium-Zinc Alloys during and after Solidification." By Professor T. TURNER (Birmingham) and D. EWEN (Newcastle-on-Tyne).
4. " On the Effect of Silver, Bismuth, and Aluminium upon the Mechanical Properties of ' Tough-Pitch ' Copper containing Arsenic." By F. JOHNSON (Swansea).
5. " On Metallography as an Aid to the Brassfounder." By H. S. PRIMROSE (Glasgow).
6. " On Magnetic Alloys formed from Non-Magnetic Materials." By A. D. ROSS (Glasgow).

On October 11, in accordance with the requirements of the Companies (Consolidation) Act, 1908, the first General or Statutory Meeting of the incorporated Institute was held, at which purely formal business was transacted.

The Council desire to record their indebtedness to the Institution of Mechanical Engineers for the courtesy shown to the Institute of Metals in granting permission to hold the Annual General Meeting, the May Lecture, and the Statutory Meeting in their building at Storey's Gate, Westminster, S.W.

Local Sections.

A notable development that took place during the past year was the sanction given by the Council to the formation of Local Sections of the Institute. The first of these Sections has been formed in Birmingham, and the first meeting of this Section took place on November 22, when a lecture was given by Mr. O. F. Hudson, M.Sc., on "An Introduction to Metallography." The Chairman of the Local Section (Mr. G. A. Boeddicker) presided.

Corrosion Committee.

Realising the vast importance to manufacturers and users of the non-ferrous metals of a knowledge of the causes and methods of prevention of the corrosion of non-ferrous metals, the Council appointed a special Committee "for the purpose of furthering the study of the cause or causes and prevention of the corrosion of metals and alloys coming within the purview of the Institute of Metals." The following gentlemen were appointed members of this Committee :—

Sir GERARD MUNTZ, Bart. (*Chairman*).
Professor H. C. H. CARPENTER, M.A., Ph.D. (*Hon. Secretary*).
G. D. BENGOUGH, Esq., M.A.
Engineer Captain G. G. GOODWIN, R.N.
Professor A. K. HUNTINGTON, Assoc.R.S.M.
J. T. MILTON, Esq.
A. PHILIP, Esq., B.Sc., Assoc.R.S.M.
LEONARD SUMNER, Esq., M.Sc.
Professor T. TURNER, M.Sc.
Sir WILLIAM H. WHITE, K.C.B., F.R.S.

The first meeting of the Committee was held on May 25, at which Mr. G. D. Bengough, M.A., undertook to prepare a summary of the literature dealing with the corrosion of metals.

A Pathological Museum of Metals.

During the year under review there was established at the offices of the Institute, Caxton House, Westminster, S.W., a pathological

museum of metals, tending to show how non-ferrous metals and their alloys may fail in use. The first contributions to the museum were received from the President, and subsequently several members were good enough to add to the collection. The Council hope that additional donations will be made to the museum by members. Cases for the housing of the specimens were presented by the President, Dr. Beilby, and Mr. Boeddicker.

PUBLICATIONS.

Three volumes of the Journal were published in 1910—Volume II. being issued to members in February, Volume III. in June, and Volume IV. in December. These contained 1100 pages of letterpress, plates, and numerous illustrations in the text. The Council are convinced that in the Journal the Institute possesses a valuable record of metallurgical progress. The Council feel that the value of the Journal is being appreciated, as the sales of copies of the Journal, both to members and non-members, are increasing very rapidly. The Journal is regularly exchanged with the Proceedings of the following Institutions :—

> Institute of Marine Engineers.
> Institution of Automobile Engineers.
>   ,,   ,, Civil Engineers.
>   ,,   ,, Electrical Engineers.
>   ,,   ,, Mechanical Engineers.
>   ,,   ,, Naval Architects.
> Iron and Steel Institute.
> Institution of Mining and Metallurgy.
> The Chemical Society.
> The Faraday Society.
> The Royal Society of Arts.
> The Society of Chemical Industry.
> Junior Institution of Engineers.
> American Electro-Chemical Society.
> American Institute of Mining Engineers.
> Department of Commerce and Labour, Bureau of Standards, Washington.
> Königlichen Materialprüfungsamt, Berlin.
> Staffordshire Iron and Steel Institute.
> West of Scotland Iron and Steel Institute.

LIBRARY.

During the year a commencement was made of the formation of a Library, and the Council has purchased certain works, including a complete set of the Proceedings of the Institution of Mining and Metallurgy, and a complete series of Reports of the Alloys Research

Committee of the Institution of Mechanical Engineers. The following donations to the Library have been received, and are gratefully acknowledged by the Council :—

Title.	Presented by—
" Alloys (Non-Ferrous)." By A. Humboldt Sexton.	The Author.
" Armstrong College Calendar."	The University of Durham.
" Engineering in the United States." By Frank Foster, M.Sc.	The Manchester University Press.
" Hütte - Taschenbuch für Eisenhüttenleute," vom Akademischen Verein Hütte e.v.	Wilhelm Ernst & Sohn.
" Metallography." By Cecil H. Desch, D.Sc., Ph.D.	Longmans, Green & Co.
" Some Modern Conditions and Recent Developments in Iron and Steel Production in America." By Frank Popplewell, B.Sc.	The Manchester University Press.
" The Corrosion and Protection of Metals." By A. Humboldt Sexton.	The Author.
" The Common Metals (Non-Ferrous)." By A. Humboldt Sexton and J. S. C. Primrose.	The Authors.

The books are kept in the Members' Room attached to the offices at Caxton House. The Council have placed in this room a framed photograph of Sir William H. White, K.C.B., F.R.S., First President of the Institute.

INTERNATIONAL CONGRESS, 1915.

At the request of the Council the President attended at Düsseldorf as a Delegate of the Institute of Metals, together with other Delegates representing other allied British scientific institutions, to extend an invitation to the International Congress of Mining, Metallurgy, Mechanics, and Geology, to hold the next meeting of the Congress in London in 1915. The President reported to the Council that the invitation had been accepted.

FINANCE.

With regard to the Report of the Honorary Treasurer, it is desirable to point out that the Statement of Accounts as presented by Professor Turner covers a period of six months only, *i.e.* from January 1, 1910, to June 30, 1910. Acting on the recommendation of the Honorary Auditor, the Council decided that the annual audit of the Institute's accounts should take place at the conclusion of each financial year (June 30) instead of, as in 1908 and 1909, at the end

of the calendar year. The new scheme was put into operation in 1910, with a result that, as mentioned above, the audit covers a period of six months only. In future, the termination of the Institute's financial year will coincide with the date of the annual audit, and the accounts for the twelve months terminating on June 30 in any year will be presented at the Annual General Meeting held the following January.

ANNUAL DINNER.

The First Annual Dinner of the Institute was held on January 18, 1910. There was an attendance of guests and members numbering about 175, amongst whom were many distinguished guests, including the Presidents of allied institutions, the Deputy-Master of The Mint (The Rt. Hon. W. Ellison-Macartney), the Vice-Chancellor of the University of Manchester (Sir Alfred Hopkinson, K.C.), and the Chief Superintendent of the Royal Ordnance Factory (H. F. Donaldson, C.B.). The Council considered the Dinner so successful that it has been resolved to hold a similar function in 1911.

The Honorary Treasurer, Professor T. TURNER, M.Sc., then read the following Report and Balance-sheet :—

Acting on the recommendation of the Honorary Auditor the account of receipts and payments now presented covers only the half year ending June 30, 1910. In future it is intended to make the financial year coincide with the period covered by the annual subscription. It will then be more easy to prepare a statement of assets and liabilities as required under the articles of incorporation. It may be noted that the balance in hand on June 30, 1910, was £323 19s. 5½d. So far as can be ascertained the total accounts owing, only part of which had been presented, amounted to £59 3s. 11d., so that the actual money assets of the Institute, after satisfying all subscribers and paying all dues, amounted to £264 15s. 6½d. The expenditure arising out of the Incorporation of the Institute have not yet been paid. On the other hand, the Institute possesses furniture and office fittings, and a valuable reserve of printed Journals, the demand for which is steadily increasing.

During the past year the expenditure has been increased in two important directions, namely, the cost of the Journal, and the provision of a comfortable Members' Room at Caxton House. To meet this increased cost it is very important that the progress in the growth of the membership of the Institute, which has hitherto been so gratifying, should be well maintained.

INSTITUTE OF METALS.

TREASURER'S ACCOUNT OF RECEIPTS AND PAYMENTS FOR SIX MONTHS ENDING JUNE 30, 1910.

RECEIPTS.

	£	s.	d.
To Balance brought forward from last Account—			
Lloyd's Bank Deposit Account £507 2 4			
,, ,, General 242 12 0			
Cash in hand of Secretary 1 4 7			
,, ,, Treasurer 1 0 9			
	£751	19	8
,, Member's Subscriptions	238	4	7
,, Sale of Journal	22	16	9
,, Sale of Dinner Tickets	53	12	6
	£1066	13	6

PAYMENTS.

	£	s.	d.
By Office Furniture and Fittings	£47	2	2
,, Expenses of Meetings	27	6	8
,, Printing and Despatching Journals	275	16	0
,, MANAGEMENT EXPENSES—			
Secretary's Salary £125 0 0			
Rent, Rates, &c. 79 15 3			
Printing and Stationery 35 9 6½			
Clerical Assistance 46 10 10			
Postages, Travelling, & Sundries 40 18 1			
Bank Charges and Cheque Book 1 2 6			
	328	16	2½
,, Expenses of Dinner	63	13	0
,, Balance carried forward—			
Lloyd's Bank Deposit Account £257 2 4			
,, ,, General 51 8 6			
Cash in hand of Secretary 12 15 1½			
,, ,, Treasurer 2 13 6			
	323	19	5½
	£1066	13	6

I hereby certify that I have audited the Accounts of the Institute for the six months ending June 30, 1910, and in my opinion the above is a correct statement of the Receipts and Payments.

G. G. POPPLETON,

CHARTERED ACCOUNTANT,

BIRMINGHAM, LONDON, AND SHEFFIELD.

December 19, 1910.   (*Honorary Auditor.*)

Professor T. Turner, M.Sc., Honorary Treasurer, in presenting his report, said that the members would notice, as stated in the report, that it was only for the half-year. Under the Companies' Act it was necessary for the Institute to present a statement of liabilities and assets, whereas hitherto it had only presented an account of receipts and payments. It was not possible in the middle of the session conveniently to prepare a statement of liabilities to the members, but by arranging for the accounts to terminate at the end of the subscription year it was possible to easily give an account of liabilities. It was chiefly for that reason that the auditors suggested a change, so that he only had to report the results of a half-year's working. It would be noticed that at the end of the subscription year, when everything had been supplied to the subscribers to which they were entitled, there was a clear balance in hand of £323. There were, however, several accounts still outstanding, some of which had not been presented ; but making allowance for every known liability, there was a clear balance in hand of £264 15s. 6½d., which was the profit on the working of two and a half years, which he thought was extremely satisfactory. He wished, however, to say that at the present moment the Institute was spending at a rate which was slightly greater than its income. This arose from the fact that the members were being given very good value for their money. That little difficulty of shortage of income was, he hoped, quite temporary, and it could be easily remedied by a slight addition to the membership. The crux of the whole question was keeping up the membership of the Institute, otherwise the Institute was at the present moment in a thoroughly sound and satisfactory condition.

The President, after formally moving the adoption of the Report and Statement of Accounts, invited the members to ask questions on any point on which they desired further information.

Mr. T. Vaughan Hughes inquired whether it was possible to extend the membership of the Institute in the direction

suggested by Mr. Walter F. Reid at the dinner on the previous evening, namely, by forming branches of the Institute abroad in a similar manner to that followed by the Society of Chemical Industry. He mentioned the point because the Treasurer had stated that the Institute was spending an amount slightly in excess of its income, and if branches were formed abroad in the manner suggested, it might mean an addition to the subscriptions available.

The PRESIDENT, in reply to Mr. Hughes' inquiry, said the Council would give close attention to the matter of the formation of foreign sections, but for the moment he did not think they were in a position to go into the question until the home sections had been completed. It was necessary first of all to get local sections established in the great commercial centres. One had already been established in Birmingham, and he was hopeful that other sections would be established in the larger towns. When those local sections had been established, he had no doubt that the Council would be able to take up the question of the foreign sections. He desired to point out, however, that the Institute already possessed many foreign members in Europe, the United States, South America, South Africa, Australia, India, Japan, and China, and those gentlemen would form nuclei around which others would congregate, so that by-and-bye it might be possible to establish foreign sections. He did not think it was quite possible, however, to take any action in this matter at present.

The motion for the adoption of the Report and Statement of Accounts was then put and carried unanimously.

BALLOT FOR COUNCIL FOR 1911.

The PRESIDENT called upon the Secretary to read the list of officers elected for the year 1911 as the result of the ballot taken in December 1910.

The SECRETARY read the following list :—

Vote of Thanks to Retiring Members of Council.

Mr. E. L. Rhead, M.Sc. Tech., in proposing a hearty vote of thanks to the retiring Members of Council, thought the members owed the Council a deep debt of gratitude for their untiring efforts to extend the influence of the Institute, which had succeeded in a very great measure, as was indicated by the results that had already been attained. The new activities that had been inaugurated in the consideration of

the important subject of the corrosion of metals led the members to believe that the interest of the Council was still as active as ever, and that the results obtained in the future would be much greater. It was, he thought, a matter for congratulation that from so small a beginning the Institute had already grown to such a size and influence. He was particularly pleased to hear in the Report read by the Secretary that the purchase of the Proceedings was increasing in extent, because it was an indication that even outside the Institute there was a very considerable amount of influence being exercised.

Dr. J. T. Dunn, in seconding the resolution, said that it must be evident to all the members that, particularly in the early days of an Institute, the making or marring of the future success of the Institute lay very much in the hands of the Council. The way in which the Institute had grown up to the present time formed in itself the best evidence the members could have of the care and skill with which the Council had attended to their duties. As the President was included in the vote of thanks, he thought perhaps it would not be altogether proper that Sir Gerard should put the motion, and therefore, with the President's permission, he (Dr. Dunn) would put the motion to the meeting and ask the members to carry it with acclamation.

The resolution having been carried with acclamation,

The President, on behalf of the retiring Council, thanked Mr. Rhead and Dr. Dunn for the very kind manner in which they had proposed the resolution, and the members for the hearty way in which they had carried it. He could only say it had been a pleasure to all the Council to do everything in their power to forward the interests of the Institute.

Election of Members.

The Secretary read the following list of names of candidates who had been duly elected Members of the Institute as the result of the ballot taken in December 1910 :—

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Almond, George (*Student*)	339 Chorley New Road, Horwich, Lancs.	Chemical Metallurgist	Geo. Hughes. C. A. Edwards. E. Millington.
Ash, Harold Edward Haydon	H.M.S. *President*, South West India Docks	Engineer-Commander, Royal Navy	Sir H. J. Oram. Henry R. Teed. P. Marrack.
Barclay, Alexander Clark	Minas Sotiel Coronada, Province de Huelva, Spain	Chemist	Sir G. Muntz, Bt. W. Gowland. T. Turner.
Bevis, Restal Ratsey	Hamptoune, Birkenhead	Civil Engineer	Sir H. J. Oram. G. G. Goodwin. P. Marrack.
Brown, James	Scotts' Shipbuilding and Engineering Co., Ltd., Greenock	Director of Scotts' Shipbuilding and Engineering Co.	Sir H. J. Oram. P. Marrack. G. G. Goodwin.
Carels, Gaston Louis	53 Dock, Ghent, Belgium	Director of Carels Bros., Ltd.	Sir H. J. Oram. Sir W. H. White. J. T. Milton.
Carlyle, William Arthur, B.A.	Grange Cottage, The Grange, Wimbledon	Prof. of Metallurgy, Royal School of Mines.	W. Gowland. Sir G. Muntz, Bt. T. Turner.
Cartland, John (*Student*)	Solihull, Warwickshire	Metallurgical Student	T. Turner. A. G. C. Gwyer. O. F. Hudson.
Corner, John Thomas, Engineer Rear - Admiral, C.B.	32 Victoria Street, S.W.	Director of Bull's Metal Co., Yoker, Glasgow	Sir H. J. Oram. P. Marrack. A. E. Seaton.
Dance, Edward Leonard	20 Lovaine Place, Newcastle - on - Tyne	Analytical Chemist	J. M. Allan. R. M. Sheppard. Sir G. Muntz, Bt.
Dawson, Stanley Ernest (*Student*)	25 Longshut Lane West, Stockport	Student of Metallurgy	E. L. Rhead. H. M. Ridge. J. A. C. Edmiston.
Dawson, William Francis	9 Adams Road, Schenectady, N.Y., U.S.A.	Designing Electrical Engineer	W. B. Parker. Sir G. Muntz, Bt. G. A. Boeddicker.
Desgraz, Adolphe	Sedanstrasse 66, Hanover, Germany	Consulting Engineer and Metallurgist	H. M. Ridge. H. L. Rhead. H. S. Primrose.
Esslemont, Alfred Sherwood	Royal Exchange Buildings, Newcastle-on-Tyne	General Manager County of Durham Electrical Power Distribution Co.	C. F. Wedemeyer. Henry Clark. C. S. Vesey Brown.
Forsstedt, James	Vestorås, Sweden	Chief Engineer, Svenska Metalvorken, Sweden	Arthur Jacob. J. T. W. Echevarri. R. Seligman.
Grazebrook, Engineer - Lieutenant Robert, R.N.	H.M.S. *Tartar*, Eastern Destroyer Flotilla, c/o G.P.O., E.C.	Chief Engineer, H.M.S. *Tartar*	Harry Kaye. P. W. Smith. Pitt Becker.
Greenwood, Vladimir Edward	Orotava, Station Road, Wylde Green, Birmingham	Assistant Manager, Birmingham Metal and Munitions Co.	G. A. Boeddicker. Cecil Leigh. W. Gowland.
Heinrich, Eugen	P. H. Muntz & Co., Ltd., Alexandra Works, West Bromwich	Director and Works Manager	Pitt Bocker. Harry Jacobs. T. A. Bayliss.

Name.	Address.	Qualification.	Proposers.
Hood, James M'Lay	Rowallan, Maryland Drive, Glasgow, S.W.	Metal Refiner	W. Paterson. John Paterson. D. M'Phail.
Hubbard, Norman Frederick Septimus, B. Sc. (*Student*)	2 Daisy Avenue, Plymouth Grove, Manchester	Metallurgical Student	H. C. H. Carpenter. C. A. Edwards. J. H. Andrew.
Hunter, Summers, Jun. (*Student*)	South Preston Lodge, North Shields	Metallurgical Student	Summers Hunter. A. Laing. J. M. Allan.
Inglis, George Alexander, B.Sc.	64 Warroch Street, Glasgow	Engineer	Sir W. H. White. J. M'Laurin. Henry R. Teed.
Johnson, Harold Carruthers, B.Sc. (*Student*)	12 Oldfield Road, Salo, Cheshire	Metallurgical Student	H. C. H. Carpenter. C. A. Edwards. J. H. Andrew.
Kidston, William Hamilton	81 Great Clyde St., Glasgow	Metal Merchant	Sir G. Muntz, Bt. A. Barr. C. H. Desch.
Levi, Clive Joseph, B.Sc.	143 Newhall Street, Birmingham	Director of Levi & Salaman, Silversmiths	R. M. Sheppard. Sir G. Muntz, Bt. G. A. Boeddicker.
Louis, Henry, M.A., D.Sc., Associate R.S.M.	4 Osborne Terrace, Newcastle - on - Tyne	Professor of Mining	Sir G. Muntz, Bt. W. Gowland. H. M. Ridge.
Low, Archibald Nicol	Merkland Works, Partick, Glasgow	Partner and Manager, Partick Brass Foundry Co.	E. Hall-Brown. William Brown. W. Paterson.
Macfee, Robert	The Caucasus Copper Co., Ltd., Batoum, Russia	Metallurgist, The Caucasus Copper Co.	E. L. Rhead. F. Tomlinson. T. Kendrew.
Maw, William Henry	18 Addison Road, Kensington, W.	Civil Engineer	Sir W. H. White. E. Ristori. Sir G. Muntz, Bt.
M'Kechnie, James	Vickers, Sons & Maxim, Barrow-in-Furness	Director of Vickers, Sons & Maxim	Sir H. J. Oram. P. Marrack. G. G. Goodwin.
Meyrick, Lewis Jenkin	137 City Road, Birmingham	Chemist, Muntz's Metal Co., Ltd.	Sir G. Muntz, Bt. R. M. Sheppard. W. Gowland.
Oakden, William Edward	American Optical Co., Southbridge, Mass., U.S.A.	Director of Research Laboratory	Sir G. Muntz, Bt. W. Gowland. T. Turner.
Onyon, William	Admiralty Controller's Department, S.W.	Engineer - Commander, Royal Navy	Sir H. J. Oram. J. M'Laurin. P. Marrack.
Paterson, William, Jun. (*Student*)	Braemar, Parkhead, Glasgow	Metal Refiner	W. Paterson. John Paterson. D. M'Phail.
Redwood, Sir Boverton, Kt., D.Sc., F.R.S.E.	Wadham Lodge, Wadham Gardens, Hampstead, N.W.	Consulting Chemist	Sir W. H. White. A. E. Seaton. Sir H. J. Oram.
Sjögren, Andreas Samuel	Svenska Metalverken, Stockholm, Sweden	Sales Manager, The Swedish Metal Works, Ltd.	Arthur Jacob. J. T. W. Echevarri. R. Seligman.
Smith, Sydney William, B.Sc., Assoc. R.S.M.	Royal Mint, E.	Assayer	O. F. Hudson. F. W. Harbord. E. F. Law.

NAME.	ADDRESS.	QUALIFICATION.	PROPOSERS.
Stevenson, Robert	72/80 Brown Street, Glasgow	Lead Manufacturer	W. R. Broadfoot. Clive Cookson. E. S. Reid.
Stevens, Victor G.	Idsall, Solihull, Warwickshire	Works Chemist	R. M. Sheppard. G. A. Boeddicker. T. Turner.
Swift, James Beaumont	46 Queen Victoria Street, E.C.	*The Mining Journal*	T. Turner. G. A. Boeddicker. Sir G. Muntz, Bt.
Tearoe, James	410 Strand, W.C.	Consulting Engineer, Queensland Government	T. Turner. Sir G. Muntz, Bt. G. A. Boeddicker.
West, Tom (*Student*)	101 Spring Bank Street, Stalybridge, Manchester	Metallurgical Student	H. C. H. Carpenter. C. A. Edwards. J. H. Andrew.
Wharton, Frederick Malcolm	The Imperial Mint, Tientsin, China	Assayer and Chemist	T. Turner. O. F. Hudson. Sir G. Muntz, Bt.
Whitworth, Leslie	2 Palace Gardens, Enfield	Engineer	H. Davidson. C. A. Klein. D. C. Highton.
Wisnom, Engineer-Commander William McKee, R.N.	Denny & Co., Engine Works, Dumbarton	General Manager, Denny & Co., Dumbarton	Sir H. J. Oram. G. G. Goodwin. James Denny.
Woodhouse, Henry	Radley House, High Street, Cheshunt, Herts.	Metallurgist, Royal Small Arms Factory, Enfield Lock	J. E. Stead. H. C. H. Carpenter. J. H. Andrew.
Woore, Harold Linton Lea	"Croydons," Epping, Essex	Proprietor of The Metal Nail Co.	Sir G. Muntz, Bt. G. T. Holloway. James H. Wilson.

ELECTION OF AUDITOR.

On the motion of the PRESIDENT,, seconded by Mr. G. A. BOEDDICKER, the retiring honorary auditor, Mr. G. G. Poppleton, was unanimously re-elected.

PRESIDENTIAL ADDRESS.

The PRESIDENT then delivered his Presidential Address, at the conclusion of which,

Dr. W. ROSENHAIN said that it was his very pleasant duty to propose a hearty vote of thanks to the President for the address he had just delivered. The duty was a very easy one, because he was quite sure that every one who had

heard the address must have been very deeply impressed
with its character and its importance. He could have
wished that the duty of proposing the vote of thanks had
fallen upon a practical rather than a scientific member of
the Institute, because it would have been good to hear
such a one say "ditto" to Sir Gerard. Coming from him
(Dr. Rosenhain), however, such an endorsement could have
comparatively little value, because his views were a foregone
conclusion on such a point. Nevertheless he hoped that
those who were working on the science of metals might take
the address of the President as the best of good omens, as
typical of a regeneration in the minds of the practical metal-
lurgical workers of the country, and as a promise of greater
appreciation and co-operation between the practical makers
and users of metals and those who endeavoured to find out
a little more about them on what was generally called the
theoretical side. He would like to say a few words on behalf
of the poor people who were obliged to express the results
of their work in somewhat technical language, which might
not always be quite as easily understood by the practical
man as they and the practical man would wish. The pro-
blems before the practical man were extremely complex,
but scientists, who tried to solve problems in the laboratory,
naturally made them as easy and as simple as they could.
They tried to solve those problems which they set themselves
as completely as possible, but the complete solution of any
problem was bound to result in complexity of ideas and
complexity of language. For instance, an elaborate nomen-
clature had been developed, and the Proceedings of the
Institute and similar Institutes possessed pages of photo-
micrographs. All that might be a burden to the flesh and
a vexation to the spirit of the man who was not accustomed
to dealing with those things, but it was inevitable and it had
to be done, because after all it was the solution of the simple
so-called theoretical problems upon which the investigation
of the complex problems of practice ultimately turned. It
was almost hopeless to tackle a large industrial problem and
investigate it in a scientific manner systematically; one was
more or less reduced to empirical methods. Rather, their

hope lay in the progress of the purely theoretical researches, which, when built up far enough, would develop practical applications, and were developing them even now in directions which could not have been foretold. So that, even quite apart from that very cordial co-operation between industry and science which the President had so ably advocated, there was hope for the practical men in such abstract things as equilibrium diagrams and photomicrographs. He merely wished to say personally how intensely he appreciated the words that had fallen from the President, and he hoped again they might be regarded as typical of the attitude of mind of the manufacturing members of the Institute. He had very much pleasure in proposing a hearty vote of thanks to Sir Gerard Muntz for his interesting Presidential Address.

The resolution having been carried by acclamation,

The PRESIDENT thanked the members for the honour they had done him by passing the resolution.

Before proceeding to the reading and discussion of the papers, there were two or three matters to which he wished to refer.

THE MAY LECTURE, 1911.

In the first place, he wished to announce that the Council had decided to establish a course of May Lectures. It would be remembered that Professor Gowland delivered a lecture in the previous May, which was of such a high grade that the Council were a little anxious as to whether they would be able to continue on the level on which the lectures started, because it was not easy to find distinguished gentlemen who were willing to give the time and trouble to preparing a lecture to deliver before the Institute. He could allay any anxiety, however, which there might be in the minds of the members by informing them that the Council had been fortunate in securing a promise from Dr. Beilby, of Glasgow, to give the May Lecture in the present year. The date, of course, would be fixed to suit Dr. Beilby's convenience, and as soon as the date was fixed the members would be informed of the arrangements that had been made.

INVITATION TO NEWCASTLE-ON-TYNE.

Then, with regard to the Autumn Meeting of 1911, first of all there was some doubt as to where the Institute should go; then it was necessary to discover whether the people in the locality would have the Institute if it wanted to go there; and finally they had to wait to be asked. He was very pleased to be able to inform the members that the Council had that morning received and accepted an invitation from the Newcastle members to make that city the venue of the Autumn Meeting. The date proposed for the meeting was the 20th and 21st September, which it was found would be the most convenient time for most of the members, especially for their scientific friends, who were engaged in instructing the youth of the country, because it was more or less a holiday season.

CORROSION RESEARCH FUND.

Before calling upon Mr. Bengough to present his Report to the Corrosion Committee, he wished to inform the members that the Corrosion Committee reported to the Council—and the Council approved of the recommendation of the Committee—that it would be necessary, if the investigation of corrosion was to be carried any further, that funds should be provided. It was unnecessary for him to point out that, as a new Institute, they were not in a position to find from their own finances sums of money for the investigation either of corrosion or anything else. The Treasurer's report, which had recently been presented, showed that at present the Institute was in a fairly sound position; but they could not afford to use their finances at present for other purposes than those originally intended. Neither did the Council feel called upon to ask the members to increase their subscriptions voluntarily in any way, but they did feel justified in calling for volunteers to assist in the investigation of corrosion, which he was sure all members felt was a subject of very great importance. Speaking as a manufacturer, it was of vital importance to the manufacturers that the investigation into the causes of

corrosion should be continued. It had been a trouble to all manufacturers for many years that the question of corrosion was not properly understood. If the manufacturer understood it at all, he generally found that the people who were going to use the metal with which he supplied them understood it a great deal less. On the other hand, the user was also in trouble, because if corrosion was set up there was no proper central authority to which he could appeal as to the reason for the corrosion. To those classes of people the work of the Corrosion Committee was of the utmost assistance, and he therefore thought many members would consider that it was proper they should voluntarily subscribe towards the continuance of the work of the Committee. With regard to the scientists, he was sure the scientific enthusiasm of that branch of their members would be sufficient, without any further inducement, to encourage them to assist the Institute in the research. His own experience of scientists was that they were the most enthusiastic of the three branches of the Institute—the manufacturers, the users, and the scientists. It was, therefore, the intention of the Council to have handed round subscription lists, which he asked the members to fill up with such figures as they felt inclined to give. The initial expenses of the investigation would be £150, but the members need not hesitate to limit the fund to that amount, because it was always easy to find a use for the money.

Papers were then read by Mr. Guy D. Bengough, M.A. (Lecturer in Metallurgy in the University of Liverpool): Engineer Rear-Admiral John T. Corner, C.B. (late Chief Engineer of Portsmouth Dockyard); Prof. H. C. H. Carpenter, M.A., Ph.D., and Mr. C. A. Edwards, M.Sc. (Manchester); Prof. C. Alfred M. Smith, M.Sc., and Mr. H. J. Humphries (London); and Mr. Andrew McWilliam, Assoc.R.S.M., M.Met., and Mr. W. R. Barclay (Sheffield).

Each paper was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the President, to the respective authors.

CONCLUDING BUSINESS.

The PRESIDENT said he was sure the members would not desire the meeting to close without acknowledging their indebtedness to their kind friends who had offered them hospitality. He therefore had great pleasure in moving the following resolutions:—

" Resolved, that the best thanks of the Institute be and are hereby tendered to the following :—

(1) The Council of the Institution of Mechanical Engineers for their courtesy in permitting the use of their rooms on the occasion of this meeting.

(2) To the Chairman and Directors of the Thames Ironworks Shipbuilding and Engineering Company, who granted permission to the members of this Institute to visit their shipbuilding yard, and for their kind hospitality.

(3) To the Chairman and Committee of the Mining and Metal-lurgical Club for their courtesy in extending the privilege of their Club membership to members of the Institute of Metals who were present in London for the Annual General Meeting on January 17 and 18, 1911."

The resolution was put and carried with acclamation.

Rear-Admiral J. T. CORNER said that before the meeting separated he was sure the members would desire to pass a vote of thanks to the President for the admirable manner in which he had conducted the business of the meeting. The present was the first meeting of the Institute he had had the honour of attending, and he had been much struck with the urbane and genial manner in which the President had carried through the business. He had the greatest pleasure in proposing a hearty vote of thanks to Sir Gerard Muntz for his conduct in the chair.

The resolution was duly seconded, and carried with acclamation.

The PRESIDENT, in reply, thanked Admiral Corner and the members for the manner in which the vote of thanks had

been proposed and carried. It had been a great pleasure to him to have the honour of presiding over the meetings. For a deaf man it was a little trying to have to preside over meetings lasting six hours, but they had been most interesting and instructive, and the papers which had been read and discussed had been fully up to the high standard the Institute had already set. He trusted that in future the Institute would continue to do well, and to live up to the standard which had been established.

The proceedings then terminated.

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VISIT.

In the afternoon of January 17 a party of about one hundred members visited the works of the Thames Ironworks Shipbuilding and Engineering Company, Limited, where H.M.S. *Thunderer* was seen in course of construction. Subsequently tea was kindly provided by the Directors of the Company. The Second Annual Dinner (a report of which is published on pp. 228—243) took place in the evening.

"THE REASON WHY"
THE QUEST OF THE INSTITUTE OF METALS.

PRESIDENTIAL ADDRESS.*

By Sir GERARD A. MUNTZ, Bart.

THE work done by the Institute during the past year in establishing a committee to investigate the causes of the corrosion of metals is one of great moment and likely to have far-reaching results in the future. As will be observed from Mr. Bengough's report to the Corrosion Committee, which report will shortly be presented, the scope of the work is such that we may anticipate many years of labour before the whole range of the subject is opened up to view, and a much longer time must elapse before the investigation has made any appreciable progress towards solving the many problems involved. In setting forth to accomplish this task the Institute has demonstrated its possibilities, and shown in what manner it can be of use to the engineering world and the public at large. It has thereby become an Institute of practical value, and ceased to be a mere association of people interested in the use and manufacture of non-ferrous metals in the abstract.

During the past year some of our original members have resigned. They were chiefly men who had been persuaded to join our Institute at its commencement by friends who were interested in our work, but they were not themselves really interested in us or our work, and therefore were not likely to be useful or active members. In spite of these resignations the Institute has more than maintained its numbers, and I think we may congratulate ourselves upon that fact, more especially because those members who have joined us, and so enabled our membership roll to be extended very considerably, are the right sort of men. They are exactly the type we want, being men who are really interested in non-ferrous metals and the researches in which we are engaged, either as users, manu-

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* Delivered at Annual General Meeting, London, January 18, 1911.

facturers, or scientists who can realise and grasp the value of our work.

Complaints have been made in various quarters that we are too much a body of scientists and not sufficiently a practical association, more especially in the papers that have been presented at the meetings of the Institute. I think that there is a good deal of misapprehension about the matter. With regard to papers, though it is interesting to have the experience of the manufacturer as to the result of his methods, and yet more interesting to learn from the user his experience in the wear of non-ferrous metals under various conditions, and the nature of the failures with which he has met, nevertheless it is after all to the scientific branch of the Institute that we should and do look for enlightenment and information, both as to the best manner in which to treat metals in the course of their manufacture, and as to the effect of certain treatments and the reasons of such effects. It is the latter which is of the greatest importance to the manufacturer.

In a similar degree the same remark applies to the user. He wants to know *why*. If he finds that a certain class of material fails without any apparently explicable reason, he wants to know the real reason of such failure. Hitherto he has been content to say, " bad manufacture," or " inferior metal," but the days when those answers seemed to suffice are past. We live in times of constant development and perpetual change in the various requirements of the engineering world, and the engineer wants sound scientific information as to what is the right thing to use in his work. He does not require simply the old rule of thumb guidance, which was good enough for his forbears ; he wants a properly worked out, well reasoned argument, and proof.

Among the members of the two—if I may so call them— practical branches of the Institute, the makers and users, how comparatively few are there who have either the requisite knowledge or time properly to investigate the scientific reasons of cause and effect. The maker knows by practice that certain processes will have certain results, as a rule, but not always. Every now and then something crops up which puzzles him and gives enormous trouble. He can see no obvious reason

for the trouble, and usually he goes blundering on, trying one thing and another to correct the evil, until finally things come right again, as often as not, just as mysteriously and just as inexplicably as they went wrong, and he goes on with his manufacture, possibly with an added experience, but with very little, if any, added knowledge as to the why and wherefore of the trouble he has encountered.

Just the same happens to the user. Failure occurs and troubles arise, and after a time he gets over the difficulty one way or another, and goes on again happily as before, but the real reason of it all has generally never been properly or satisfactorily cleared up.

That is an altogether unsatisfactory state of affairs, because though in both cases the immediate trouble may have been got over, it is always liable to recur, and the whole process of attempting a solution of the mystery will have to be gone through again. What is really needed is a scientific exploration, and if possible explanation. Given that, the recurrence of the difficulty can almost certainly be avoided, or if it occurs it can be at once tackled on definite lines. The causes being known as well as the remedy, it is generally comparatively easy to apply the latter and stop the trouble at once.

It is to our scientific brethren that we must look for the elucidation of these mysteries, the working out of the cause and effect, and the finding of the true remedy and the *reason why*. It is that "reason why" that we need most of all to know.

Therefore I think that it is a mistake to complain that the papers which have been read before this Institute have been too scientific. Possibly in some cases the grade of science has been too high to be of value to all our members, but amongst both users and makers there are those who have a sufficient general knowledge of the scientific side of metallurgy to be able to draw valuable lessons, even from such papers as those. On the other hand, we have had papers so simply expressed that though the science in them was of the utmost intricacy, yet any one could understand what they were intended to convey, and therefore would be enlightened and assisted. The difficulties met with in both the manufacture and usage of

non-ferrous metals are legion, and the causes of these troubles are often exceedingly obscure. It is often some very minute matter which has been the cause of our trouble, often something quite simple if we only knew it. But it has hitherto been the want of that little bit of necessary scientific knowledge which has left matters in such a hopeless muddle. If a man does not possess sufficient metallurgical knowledge himself, or lacks the necessary apparatus, or has not the requisite time for carrying out such investigation as will teach him the true reason of his troubles, let him send his samples, together with all the information he can obtain on the subject, to one of his scientific associates, and arrange for him to make a thorough research, and, as far as he is able from the information obtained, suggest a reason. Thereafter it is fairly simple to follow the quest further and practically test the accuracy of the theory propounded. I speak from experience on the subject, for I have on more than one occasion tried this method of elucidating difficulties when at a loss to work out explanations for myself, even with the aid of first-class apparatus and a tried staff.

The old saying that "two heads are better than one" holds very true in cases of this sort. A man who investigates for himself is apt to start with preconceived notions, and will try to prove his theory correct—thereby often going hopelessly astray; whereas another man, coming fresh to the subject, with no bias in any special direction and an open mind, may alight on some clue which the other, following out his previous theories, may easily have missed.

To such of us as are either users or makers, and have the necessary laboratories and staff to carry out research for ourselves, I feel sure that the highly scientific papers that have been presented to the Institute on the subject of micro-photography, and the light it throws on the treatment of metals, must have been of immense value. The science of microphotography is yet young, but it is one which may be of stupendous importance to the non-ferrous world in the future, if properly used. The extraordinary effect of very small admixtures of a metal or of metals other than those which are supposed to constitute the metal or alloy with which we

are dealing is one of which we all have experience. Analysis will generally tell us what it is that is doing the mischief; but analysis alone will not tell us what has happened within the metal, or why the effect takes place. Add, however, the knowledge obtained by micro-photography to that given by analysis, and matters are very much simplified. The microscope shows us what a small addition of a foreign element may do in the way of crystal formation; or, again, it will show us what the effect of heat treatment, or work, or strain may be on our metal. Thus we arrive at a sound basis on which to work—a basis on which we may modify our practice and control our processes of manufacture, and decide upon what is necessary to obtain the most suitable material for our use for any given purpose under set conditions. The whole intention of the formation of the Institute was, that we should obtain a greater insight into the nature of non-ferrous metals, their behaviour, and their proper treatment. The user can tell us what his experience is in the use of various metals and alloys. The manufacturer can, if he chooses, inform us what he does to produce his various goods; but without the scientific explanation such knowledge is of little value. What is required is such knowledge as will ensure the user always getting the best material for his work, and will enable the maker to turn out consistently and regularly without any unaccountable variation, such materials as shall meet the requirements of the specification under which he has to work.

It is therefore to be hoped that the mistaken idea that the Institute is not fulfilling its proper mission unless its papers are more devoted to the experience of the users and makers, will cease to endure, and that it may be understood that, though papers from the makers may be interesting, and accounts of users' experiences may be useful, yet the chief basis of our work should be and must be, if we are to carry out the original object of our association, the obtaining of knowledge: the scientific exploration of everything that happens in the sphere of either the manufacturer or the user, and the reason of such happenings. There can be no question that the Institute has done yeoman service to its practical members in throwing light, through the scientific papers that have been

presented, on difficult questions which have troubled both users and makers alike in the past, and will continue to trouble both until they bring their practice into line with the reasoning of science, and cease to be content with the rule of thumb methods and the principle of " follow my leader."

We have reason to hope that our Corrosion Committee will help us in arriving at the " reason why " in one direction, and help to clear up problems which have hitherto been mysteries to most of us, causing endless vexation, annoyance, and expense. When that committee is firmly established, there is no reason why other committees should not undertake work that is waiting to be done in other directions. There remain many fields for exploration. Possibly the most obvious of all concerns the effect of heat treatment and work on metals. I think that we may be well satisfied with the progress which the Institute has already made in the two eventful years of its existence. It cannot be denied that it has fully justified its creation already, and has prospects of advancing in new directions, increasing in usefulness and doing most helpful work in the future. I believe that the Institute has a great future before it, and that when those of us who are now active in aiding its development have long passed away, it will be flourishing, still reaching out for new metallurgical worlds to conquer, so that it will be marvelled at by manufacturers and scientists of that day how it came about that their predecessors were so tardy in coming to the obvious conclusion that an Institute such as this was the only sane means of ensuring steady progress in action and thought for all concerned in the manufacture and use of the non-ferrous metals.

A REPORT

TO THE

CORROSION COMMITTEE

OF THE

INSTITUTE OF METALS.*

By GUY D. BENGOUGH, M.A.,
LECTURER IN METALLURGY IN THE UNIVERSITY OF LIVERPOOL.

PREFACE

THIS Report to the Corrosion Committee of the Institute of
Metals is intended to give a general review of the present
knowledge of the subject of the corrosion of non-ferrous
metals, both in its practical and scientific aspects. It is
believed to be the most comprehensive monograph on the
subject that is available.

The author points out several important gaps in our know-
ledge which, in his opinion, call for immediate attention.

The theory of corrosion is considered in some detail, and an
attempt is made to lay a broader scientific foundation for the
whole subject. Two series of experiments are proposed, which,
in the author's opinion, should be taken in hand at once.
One series is of an empirical nature, and is intended to test
the validity of certain opinions held on the subject by prac-
tical men, and especially such opinions as are in dispute
between different authorities. The other series of experiments
is of a purely scientific nature, and is regarded as a means of
elucidating certain causes of corrosion that have hitherto been
obscure.

INDEX.

* Presented at Annual General Meeting, London, January 18, 1911.

SECTION I.

INTRODUCTION.

THE pitting and corrosion of metals and alloys is probably one of the most serious troubles with which the modern engineer has to contend. In the case of iron and steel, as used in boiler construction for instance, these phenomena may be attended with dangerous and even fatal consequences, as the history of the subject too amply testifies. Past experience clearly shows that all the forms in which iron and steel come on the market are peculiarly liable to corrosion, and the classical researches into its causes which have been carried out in America by Cushman, Gardner, Walker, and Whitney, point clearly to the fact that only palliative and not prohibitive measures are likely to be available in the near future.

The employment of non-ferrous metals in place of iron was, in the past, adopted for the express purpose of lessening the trouble due to corrosion, for it was long ago recognised that these metals were less corrodible than any form of iron or steel. They were also used to prevent the adhesion of barnacles and other forms of marine life to wooden ships, and to resist the attacks of *Teredo navalis*. As far back as 1761 the British Admiralty used copper on the hulls of sea-going vessels for the submerged parts. Muntz metal was introduced to replace copper for this purpose in 1832, and soon after the introduction of steam machinery, copper and its alloys superseded cast iron for piping and other subsidiary purposes. In addition to the longer life of the copper and alloy fittings, they afford the advantage of smaller weight and bulk.

In the early days of the use of copper and its alloys little trouble was met with from corrosion or pitting, which last is merely intense and localised corrosion. It is frequently stated that trouble has only arisen in the last few years. An examination of the literature of the subject, however, shows that this is not altogether correct. For instance, in 1823 Robert Mushet took out a patent for the manu-

facture of a corrosion-resisting alloy suitable for sheathing which consisted of copper containing $\frac{1}{8}$ per cent. of tin, or zinc; and as early as 1824 Sir Humphry Davy * carried out a series of experiments on the best means of protecting the copper sheathing of ships from the corrosive action of sea-water.   The records of the American Society of Naval Engineers show that serious and frequent trouble was met with in the case of copper sheathing on wooden vessels between the years 1847 and 1850.   After this the trouble seems to have become rather less frequent.   It broke out again about the year 1876, when the Admiralty first met with the difficulty in the case of some propeller bolts used in the construction of a wooden ship named the *Frederick William*, and was continued into the eighties.   A renewed attack, of a still greater degree of virulence, broke out about the year 1900, since when it seems to have become endemic.

Like the plague, then, the trouble has, in the past, been periodical, and this has led to the idea that it is in some way connected with the predominating sources of the copper ore used in each period.   The data and records available, however, are too scanty to allow of a thorough examination of this theory.   It is now mentioned on account of its possible connection with another suggested cause of corrosion.

Unfortunately we are, at the present moment, in the midst of a period of singular activity on the part of the corrosion demon, or perhaps we should say, of his modern equivalent, the corrosion bacillus.   At any rate, we seem to be now, more than ever before, susceptible to his attacks, and it is therefore peculiarly fitting that a determined and organised attempt should be made to resist his onslaughts.

The Corrosion Committee of the Institute of Metals has been formed "for the purpose of furthering the study of the cause or causes and prevention of the corrosion of metals and alloys coming within the purview of the Institute.   The field of work here indicated is obviously of very wide extent; so wide, in fact, that there is little hope of its being completely explored in less than a decade or two.   This being well understood by the members of the Committee, it became

* *Philosophical Transactions*, 1824.

necessary to select some one small portion of the field upon which to make a start. In the first instance, therefore, it has been decided to make a special study of the corrosion of 70 : 30 brass. This alloy comes into commerce in the form of such important products as condenser tubes for marine and stationary engines, and of cartridge cases of all sizes. It has generally been considered to be a stable, homogeneous, solid solution, though some considerable doubt has been thrown upon this view by recent work.* Probably it is not a chemically stable body, even at the ordinary temperature, and at the higher temperatures at which it is used in condensers, any change which it may undergo will proceed at an enhanced rate; in consequence, its behaviour towards corrosive agents will probably be affected. In addition to this it does not, as a rule, dissolve or corrode as a whole, but exhibits the phenomenon of a preferential solution of zinc. Hence we are dealing with an alloy whose surface is of a progressively changing composition. The question immediately arises, In what manner does this action take place, and what is the state of aggregation of the metals in the solid alloy? Unfortunately, at the present time these questions cannot be fully answered. The electrode potential and solution pressure of an alloy such as 70 : 30 brass cannot be calculated, and the experimental determination of the data is attended with serious difficulties. As will be seen later, the data in question are of considerable importance in the study of corrosion problems.

In the case of copper, on the other hand, the data have been ascertained with a fair degree of accuracy, and it might, therefore, seem better to begin investigation with that metal; but the importance of the practical problem is so much greater in the case of brass, that it has seemed best to the Committee to endeavour to throw some light on it at as early a date as possible. It will, however, probably be found necessary to conduct a series of experiments simultaneously on the two materials, and suggestions to this effect are put forward in the latter part of this report. Strictly scientific

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* *Journal of the Institute of Metals,* vol. iv. p. 115 ; Carpenter in discussion on Bengough and Hudson's paper.

experiments, as a basis for future work, are proposed in the case of copper. In the case of brass, the experimental scheme is of a more empirical nature. It is hoped that the first series will assist in interpreting the results obtained by the second.

It may not be out of place to remark here that the empirical method has frequently proved its value in attacking industrial problems. For instance, much of the work carried out in America by Cushman, Gardner, and others, on the corrosion and preservation of steel and iron, may fairly be described as enlightened empiricism, guided in its general direction by the electrolytic theory of corrosion. It has already produced interesting and highly important results, and is likely to add to them in the near future, as the results of experiments now running come to hand.

Before actually starting any extended course of experimental work, it has been considered desirable to present in convenient form a comprehensive statement and review of our knowledge of the corrosion problem, both in its theoretical and in its practical aspects. The present report has, therefore, been prepared to meet this requirement. In Sections V. and VI. of the report, the personal views of the author, derived from a study of the available literature and from his own experiments, are presented, together with suggestions for a course of experimental investigation, which might, with advantage, be immediately taken in hand.

The present author believes that it is only by means of the active co-operation of all concerned in the handling of metals—makers, surveyors, and users alike—that a complete knowledge of the causes and means of prevention of corrosion is ever likely to be attained. A study of the present report will probably astonish many readers by the contradictory nature of the views expressed in the literature of the subject. Undoubtedly this may be accounted for, in part, by the too restricted view of the subject obtained by some of the authors as a result of the lack of the co-operation that is now being advocated. Chemists, manufacturers, and engineers all view the subject from rather different standpoints, and with different mental equipments. It is surely not unreasonable

to hope that a Committee composed of all these elements, and gathering information from every available outside source, will be more successful in directing an attack on the intricate problems of corrosion than any of the individual authors who have hitherto worked upon the subject.

SECTION II.

Review of the more important Technical Papers.

[In many cases it is almost impossible to give an adequate idea of the substance of a paper in the small amount of space that is necessarily allotted to each. Where possible the conclusions reached by each author are presented in his own words; for more detailed information readers are referred to the original papers.]

Subsequent to what we may call the Renaissance of the corrosion problem in the late seventies of the last century, the first paper, as far as I have been able to ascertain, which deals more particularly with the technical problem is one by Tilden,* who in 1886 carried out a considerable number of experiments upon the action of acids and sea-water on copper and brass. The principal conclusions which he drew from the results of these experiments were as follows :—

" 1. Copper, and brasses containing more than about 60 per cent. of copper, are attacked by sea-water and chlorides generally more rapidly than brasses containing about that proportion of copper.

" 2. One cause of unequal corrosion, leading to pitting, is the voltaic action which is set up in consequence of contact with particles of other less positive metals or metallic oxides. Oxide of copper appears to be, in the presence of salt water, one of the most active of these substances.

" 3. Another, and probably the most destructive agent of all, is the green crust of basic chloride which is formed " as described elsewhere. It is formed most abundantly when the surface is " alternately wetted with salt water and dried in the

* *Journal of the Society of Chemical Industry*, 1886, vol. v. p. 84.

air." The action of this substance may be "partly due to its electro-negative character," . . . but "the greater part of its action seems to be a chemical one, aided by its porous texture, in consequence of which it rapidly absorbs moisture and air. . . . The holes in sheathing and condenser tubes supplied by sea-water are formed, generally, in consequence of the formation of patches of this substance. The process is easy to imagine. Suppose the flow of water through the condenser tubes be interrupted for any reason. The tubes lie in a horizontal position. and do not drain completely; a small quantity of sea-water is left which speedily dries up in spots, which necessarily lie along one side of the tube in the position in which the holes are most commonly found. Then the moist salt with the oxygen of the air acts on the surface of the metal, producing a spot of oxi-chloride, which remains attached to that part and continues to act electrochemically when under the influence of the water, chemically by absorption of oxygen when dried up.

"4. There are several practical lessons of importance which may be learnt from this inquiry; the chief of these is the means of keeping the surfaces of copper and alloy as clean as possible. In the case of condenser tubes, I should imagine there would be no serious difficulty about clearing them out, every time the vessel comes into port, and before they have time to dry inside, by brushing out with a stiff brush. . . . Another point is the desirability of avoiding distortion of the metal by bending, boring or otherwise. . . . Lastly, contact with other metals should never be permitted in structures which are to be used in connection with sea-water or well-water containing large quantities of chlorides and other salts."

A report upon the causes of the explosion of a copper pipe which occurred in the s.s. *Prodano*, was made by Arnold in 1898 on behalf of Lloyd's Register of British and Foreign Shipping.* As far as the present author has been able to ascertain, this has been the first case of corrosion in non-ferrous metallurgy to be investigated by the aid of the microscope, and a special interest is attached to the report on

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* *Engineer*, vol. lxxxv., 1898.

this account. The conclusions arrived at by its author are important, and they have exercised considerable influence on many subsequent investigations.

The cause of the explosion was found to be a deterioration of the brazing metal used in the manufacture of the pipe, and it had become quite porous and brittle. The report deals mainly with the causes of this deterioration. Ordinary brazing metal as supplied by manufacturers was found to consist of equal parts of copper and zinc; in a laboratory experiment, similar material having a composition of 56 per cent. of copper was made. This was melted with borax with the object of treating it similarly with the treatment of brazing solder on the practical scale. A subsequent analysis showed that the percentage of copper had risen to 62. The deduction is drawn that the original brazing of the pipe would have had approximately this composition. An analysis of the deteriorated brazing gave:

	Per Cent.
Metallic copper	76·8
Zinc oxide	22·5
Fatty acids	1·4

showing that the deterioration is due to dezincification.

Arnold states his conclusions as follows :—

" 1. That the brazing metal was originally sound and of good workmanship, and consisted of a suitable alloy.

" 2. Explosion was due to a gradual removal from the greater part of the brazing of about half its zinc, the remainder being converted to oxide, and thus leaving a spongy and hence brittle mass of metallic copper possessing little cohesion.

" 3. That the disintegration described in the last paragraph was electrolytically brought about by the presence in the pipe of water containing small quantities of fatty acids which formed organic salts of zinc, either fusible at the temperature of the pipe or soluble in hot water.

" 4. That the fatty organic acids must have reached the main steam pipe *viâ* the piston rods, cylinders, condensers, and boilers, and that fatty oils must have been employed either inadvertently as adulterations in mineral oil or deliberately in the form of lubricants, such as tallow and castor oil."

Cohen,[*] in 1902, presented an interesting summary of his researches on corrosion problems to the Institute of Naval Architects.   He states that the companies and engineers who have supplied him with information give very contradictory accounts, even of the facts of corrosion, and that consequently the conclusions they have come to are equally conflicting. This statement, in the opinion of the author, might well be extended to include the literature of the subject, one of the features of which is its confusing and contradictory character. Cohen's results and conclusions may be briefly summed up as follows :—

1. Chemically pure copper is attacked by sea-water only in the presence of air.   If carbon dioxide is removed, no action takes place.

2. This statement applies also to ordinary electrolytic copper, sheet copper, hammered copper and cast copper.

3. In the case of brass containing :

	Per Cent.
Copper	66·6
Zinc	33·4

the presence of carbon dioxide was equally necessary to any attack by sea-water.   Both copper and zinc pass into solution, but in what proportion is not stated.

4. Metallic tin is corroded when attacked by sea-water and air.   Ordinary tin-plated condenser tubes are protected by a layer of tin only $\frac{1}{50}$ millimetre thick.   (Average of tubes of several different manufacturers.)   Even in new tubes this layer is not always uniform, but exhibits circular spots where the brass is bare.

5. Metallic nickel and cupric oxide resist even a prolonged attack by air and sea-water.

The following methods of preventing corrosion are suggested at the end of the paper :—

"(a) A thick coating of tin on copper or brass tubes.

"(b) A coating of oxide of copper.   (It is not certain, however, that this remedy is of practical application.)

"(c) A coating of nickel or, preferably, tubes entirely made of nickel.

* *Journal of the Institute of Naval Architects*, vol. xliv., 1902 ; also *de Ingenieur*, 1910.

" (d) An electric connection between copper and brass tubes, and zinc or iron plates suspended in the sea.

" (e) A continuous electric current, accurately controlled, passing through the condenser tubes or through the parts of the tubes which have to be protected against corrosion.

" (f) Insulation of the tubes from all parts of the installation in which currents flow."

During the discussion on this paper, Mr. A. F. Yarrow presented a table of results obtained by Messrs. Yarrow & Company. This table is of considerable interest, and is reproduced here.

Experiments with Condenser Tubes by Messrs. Yarrow & Co.

Kind of Tube.	How Tested.	Loss per Square Inch per Ten Days in Milligrammes.
Ordinary brass condenser tube	Sealed with boiled sea-water and hydrogen.	0·06
	Sealed with boiled sea-water and air	0·14
	Sea-water open to air	1·54
	Sea-water with air bubbling through	1·82
	Sea-water at 100° F., and open to air	1·54
	Sea-water at 10 lbs. pressure	1·27
	Plain water at 10 lbs. pressure	0·20
	Distilled water at 10 lbs. pressure	0·16
Tinned brass condenser tube	Sealed with boiled sea-water and air	0·11
	Sea-water open to air	0·54
	Sea-water with air bubbling through	0·66
	Sea-water at 100° F., and open to air	0·88
Nickel-plated brass condenser tube	Sealed with boiled sea-water and hydrogen	0·04
	Sea-water open to air	0·45*
	Sea-water with air bubbling through	0·36
	Sea-water at 100° F. and open to air	0·55

* This one had pits due to defective nickel plating.

A. W. Stewart * gives an interesting account of investigations made on behalf of the authorities of the Russian volunteer fleet. The trouble occurred in nine different ships, and was met with principally in the bilge suction and discharge pipes, and occasionally in the salt-water service pipes. The pipes were of lead, copper, or iron; little trouble was met with

in the brass condenser tubes. The engineers of the fleet were of opinion that the trouble was caused through leakage from the electric light system, and this point was investigated by Mr. Stewart. He arrives at the conclusion that stray currents had nothing whatever to do with the corrosion in any of the cases examined. His final conclusion is that the corrosion was due to attack by acids contained in the bilge water and the oils used in the engine-room.

He advises that the following precautions be taken to minimise corrosion :—

" (*a*) Avoid mooring ships in foul harbours or docks or near sewage-pipe discharges.

" (*b*) Avoid leaving the condenser full of circulating water when not in use, and when using dock or harbour circulating water.

" (*c*) Avoid the use of iron or steel in any of the sea-connections or pipes leading from the inlet end of condenser, and thus avoid oxide of iron being carried into the tubes.

" (*d*) When washing out boilers, bilges, &c., in dock, precautions should be taken against drawing all the impurities through the condenser.

" (*e*) Avoid, as much as possible, in the design of the condenser, the admitted steam striking directly against the tubes."

His general conclusions on the subject of corrosion in the case of the steamers of the Russian fleet were as follows :—

" (*a*) Electricity, as supplied for lighting, fans, and bells, has not been responsible for corrosion.

" (*b*) The system of wiring, double or single, has not been responsible.

" (*c*) The corrosion of pipes, &c., is principally due to the quality of engine-room oils in use.

" (*d*) Olive oil should not be used for lubricating purposes.

" (*e*) No vegetable or animal oil should be used for lubricating purposes on board ship, and as little tallow as possible should be used.

" (*f*) A good quality of mineral oil should only be used.

" (*g*) Engine-room, bilge, and discharge pipes should be taken out and thoroughly cleaned by removing the greasy deposit, and washed out with caustic soda.

" (*h*) Engine-room bilges should be thoroughly cleaned out and washed with caustic soda.

" (*i*) Unless conditions *g* and *h* are thoroughly carried out corrosion will not be immediately stopped by the use of good mineral oil."

The above conclusions have been given precisely as stated by Mr. Stewart. The experimental evidence which he has marshalled to support them will, perhaps, not be considered quite conclusive by every reader of his paper, even in the cases of the ships examined by him. In any case, caution should be exercised in applying these conclusions generally to other cases. In particular, it should be noted that the conditions which determined corrosion in these ships were somewhat exceptional, since the condenser tubes, which are the main sources of trouble in most cases, were not attacked.

Granting, too, that the fact has been proved that, in the case of the ships of this fleet, the electric lighting circuits had no effect in hastening corrosive action, the account given of the nature of the attack by acid on the metals does not appear to be strictly accurate. The true mechanism of such attacks is dealt with in a later section of this report.

One of the fullest and most important papers, both from a theoretical and practical point of view, is that published by Milton and Larke * in 1903. The authors begin by referring to the erratic action of corrosion : " Considerable trouble arises in certain cases ; while in others, in similar cases, no such results occur." This apparently erratic nature of the corrosive action is the most important feature of the whole problem, and upon it attention should be concentrated in all future investigations. It would perhaps be better to take the view that it is the conditions which are only apparently similar, and not the action which is erratic, and to start investigations on this assumption. Milton and Larke give details of numerous cases of corrosion of brass, Muntz metal, and cast iron, and also analyses of the new and corroded metal. The following table taken from the paper is reproduced here to show the selective action of the corrosion, zinc being dissolved by preference :—

*Analysis of Sound and Unsound Portions taken from Tube and
Diaphragm Plates of a Condenser using Sea-water.*

Description.	Copper.	Zinc and Zinc Oxide.	Iron.	Tin.	Lead.
Tube-plate—sound portion	59·07	39·07	1·01	0·22	0·63
,, ,, unsound portion	82·17	17·26	0·22	0·31	0·04
Diaphragm plate—sound portion . . .	61·48	38·28	0·08	trace	0·16
,, ,, unsound portion . .	69·87	29·85	0·12	trace	0·16

The alloys were duplex in structure, and consisted of α and β crystals. In the earlier stages of corrosion the attack was found to be practically confined to the zinc rich or β constituent, which formed local couples with the α crystals.

The authors examine at some length the question of the corrosion of condenser tubes, which usually consist of a single constituent, such as $70:30$ brass. They point out that deterioration usually occurs on the water side, but does occur occasionally on the outer side; and these cases may probably be due to erosion by the steam. When corrosion takes place on the water side it may be localised, forming a pit; or it may occur chiefly in grooves, or it may proceed practically uniformly over the whole surface. In all cases dezincification is evident. Pitting is accounted for by the authors by the erratic distribution of impurities in the brass; longitudinally corroded grooves by the drawing out of such impurities during the process of manufacture; and uniform corrosion is regarded as an unavoidable characteristic of the alloy. Particular attention is paid to the impurities which separate out from the solid solutions of copper and zinc, and are visible under the microscope as separate phases. Lead is held to increase corrosion materially; iron to a less degree; tin is considered to have a distinctly protective action, even when present in quite small quantities. The authors summarised their results as follows :—

" 1. ' Decay ' is more frequent in metals which have duplex or more complex structures than in those which are homogeneous.

" 2. ' Decay ' is due to slower or less energetic action than that causing ' corrosion '; moreover, it requires an action

which removes part only of the constituents of the metal, whereas ' corrosion ' removes all the metal attacked.

" 3. Both ' decay ' and ' corrosion ' may result from chemical action alone, or from chemical and electrolytic action combined.

" 4. ' Pitting,' or intense local corrosion, is probably often due to local segregation of impurities in the metal; it may also, in some places, be due to favourable conditions furnished by local irregularities of surface or structure producing local irregularities in the distribution of galvanic currents.

" 5. For brass exposed to sea-water, tin is distinctly preservative, while lead and iron are both injurious, rendering the alloy more readily corrodible. The percentage of the two latter metals should therefore be kept as low as possible in all brass intended for purposes where attack by sea-water is unavoidable.

" 6. With a view to obtain a minimum of corrosion, the internal surfaces of condenser tubes should be as smooth and uniform as possible; and in order to ensure this condition the cast pipe from which they are drawn should be smoothly bored inside, either before the drawing is commenced or in an early stage of the process, as is done in the manufacture of brass boiler-tubes.

" 7. Experiments with an applied electric current show that electrolytic action alone, even where exceedingly minute currents are employed, may result in severe corrosion or attack. Every effort, therefore, should be made to prevent such action by careful insulation of all electric cables; where galvanic action is unavoidable through the proximity of different metals exposed to the same electrolyte, the currents resulting should be neutralised by the application of zinc plates in the circuit so arranged that they will be negative to both of the other metals."

Very interesting appendices are given with this paper, which should be carefully studied in the original by all interested in corrosion. This paper with its appendices will, in the present author's opinion, give the best general view of the problem of corrosion to readers who have only a very limited time for study at their disposal.

Diegel [*] has published three papers on the corrosion of metals in sea-water. The first deals mainly with the effect of nickel and phosphorus on the rate of corrosion of mild steel. The plates were suspended in the harbour at Kiel, both singly and in pairs, the members of which were of different composition. The results obtained pointed to the conclusion that both phosphorus and nickel had a protective action on the steel. The experiment of adding phosphorus to a copper-zinc alloy was also tried, and in this case the effect of the phosphorus was again to slow down corrosion. Diegel therefore concludes that impure metals and alloys do not corrode faster in sea-water than pure ones. This generalisation appears to be too sweeping. In his second paper he reaches the conclusion that in the high-zinc brasses the addition of nickel has a retarding effect on corrosion. Rhodin, on the other hand, has arrived at an exactly opposite conclusion—namely, that nickel is one of the worst metals in accelerating corrosion. In many respects Diegel's results appear to be at variance with those obtained by the majority of other workers.

Sexton has contributed an interesting paper on the corrosion of condenser tubes to the *Engineering Magazine*.[†] He gives the following analysis of the deposit found in corroded brass condenser tubes:—

	Per Cent.
Copper oxide	30·85
Copper chloride	3·20
Zinc oxide	30·80
Iron oxide	11·40
Insoluble matter	3·08
Organic matter, CO_2, H_2O	20·67

He points out that the analysis shows the deposit to be a basic chloride and carbonate of copper and zinc. The copper and zinc are present in it in nearly equal quantities, though in the original tubes they were present in the ratio of 7 : 3 ; hence dezincification has evidently taken place. The iron oxide, insoluble matter, and organic matter must evidently have been derived from some source other than the tube itself.

Sexton states that in numerous experiments carried out by him on the action of sea-water on 70 : 30 brass, zinc was dissolved preferentially to the copper in every case; usually five or six times as much zinc was dissolved as copper. The action is rapid at first; thereafter the green deposit, especially if it be strongly adherent, seems to protect the alloy from further action (*cf.* Tilden's results).

When the alloy contains less than 66 per cent. of copper, Sexton finds the action to be very different, and the deposit to be white, consisting almost entirely of zinc salts; in tubes consisting of copper 66 per cent. and zinc 34 per cent. the ratio of zinc dissolved to copper was as 146 : 1 in one case, and 214 : 1 in another (*cf.* Lincoln's results).

Sexton considers that the use of specially pure metals in the preparation is not a disadvantage (*cf.* Muntz), and that stray currents may be an occasional but not frequent cause of corrosion.

Sexton's final conclusion is that irregular and rapid corrosion is due to electrolytic action set up by contact between the brass and substances electro-negative to it. Such substances are frequently introduced into the tubes from outside, and may consist of cinders, fragments of cast iron giving rise to graphite deposits, charcoal, &c. He considers that corrosion may be prevented to a great extent in the following ways:—

1. By high speed of circulating water; this will prevent the settling on the tube of the electro-negative particles mentioned above (*cf.* Isherwood).

2. By frequent cleaning of the tubes.

3. By always emptying the tubes when the steamer is at rest in port.

Rhodin [*] has published two papers and carried out a considerable series of laboratory experiments, especially on copper-zinc alloys. In his first paper he attempts to find a formula giving the rates of corrosion of the two constituents in any alloy. Thus he states: "We may suppose that the electrolytic dissolution rates of brass are directly proportional to the heat of the formation of the ultimate compounds, and to the electrical conductivities of the metals which

dissolve. As the specific conductivities are given per volume, these factors have to be divided by the densities of the metals. . . . The electrolyte, principally sodium chloride, being highly dissociated, there is no vital objection to employing the thermo-chemical reasoning on total work, without introducing Nernst's theory of partial dissolution pressures. We may proceed to calculate as follows :—

Percentage of copper dissolved $= x$

,,   ,,   zinc   ,, $= 100 - x$

Then
$$\frac{x}{100 - x} = \frac{2(WCu \underset{\rightharpoonup}{\leftharpoonup} Cl)KCu}{dCu} : \frac{WZn \underset{\rightharpoonup}{\leftharpoonup} Cl_2 KZn}{dZn}$$

Where $WCu \underset{\rightharpoonup}{\leftharpoonup} Cl =$ molecular heat of formation of $CuCl$,

$KCu =$ conductivity, dCu density of Cu

$WZn \underset{\rightharpoonup}{\leftharpoonup} Cl_2 =$ molecular heat of formation of $ZnCl_2$

$KZn =$ conductivity, dZn density of Zn.

This worked out gives $x = 62\cdot29$

$100 - x = 37\cdot70$

If copper dissolves as cupric ion we get $x = 59\cdot3$

$100 - x = 40\cdot7$

The mean is : copper $= 60\cdot8$ and zinc $= 39\cdot2$.

He deduces that alloys with a larger proportion of copper will lose copper preferentially — alloys richer in zinc will lose zinc. This conclusion, however, though several times repeated in his papers, is quite contrary to experience, at least as far as the industrially important alloys of brass are concerned. In addition to this, his argument appears to be based on faulty premises, for the electric conductivity, which occurs as a factor in his formula, given above, has little bearing on the question of relative corrodibility, and, in consequence, the value of the formula is destroyed. Nevertheless, some of his experimental results on dissolution rates are of considerable interest, as showing whether or not preferential solution of one of the constituents of the alloy takes place. Some of his curves are exhibited in Fig. 1. Flat curves, such as Nos. I. and II. in the figure which correspond respectively to copper and bronze with 10 per cent. of tin, show that these alloys go into solution uniformly—that is, that the two metals constituting the alloy pass into solution in amounts proportionate to the quantity of each metal present. Steep curves, on the other hand, show that one of the

metals is preferentially attacked at an early stage of the process, for the amount of the hydrogen given off in unit time does not become constant till some considerable time
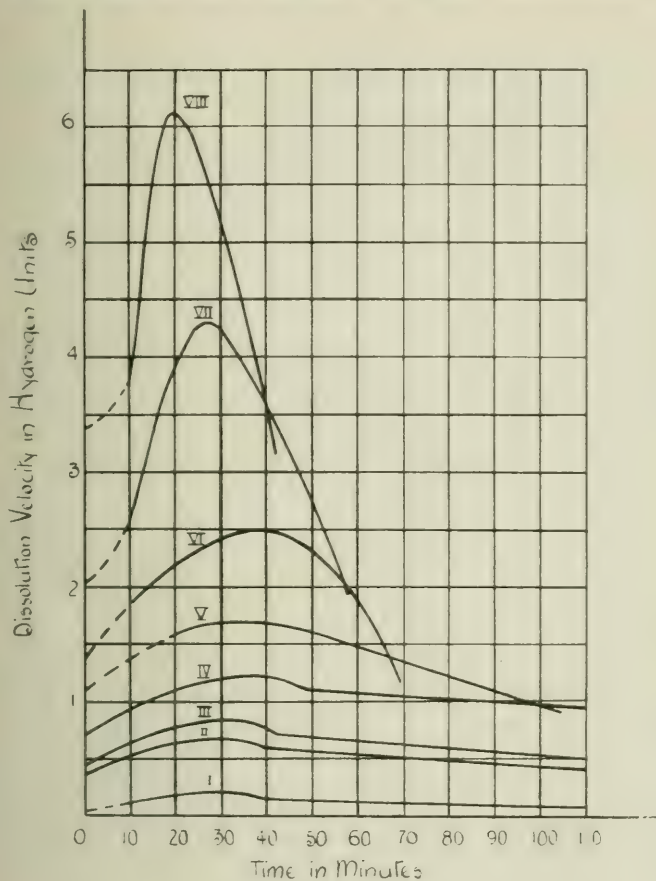
FIG. 1 (Rhodin).

I. Copper of good quality.
II. Bronze (90 per cent. Cu, 10 per cent. Zn).
III. Admiralty gun-metal.
IV. Muntz metal.

V. Brass (70 per cent. Cu).
VI. Low percentage brasses rich in Fe.
VII. and VIII. Low percentage brasses of manganese bronze type, containing incompatible materials.

after the alloy has been plunged into acid. The statement that the shapes of these curves, which merely show the variation in the evolution velocity of hydrogen when acted

upon by ten times normal hydrochloric acid at 80° C., will also indicate the relative corrodibility of alloys under service conditions, does not seem to be necessarily true, and certainly cannot be accepted without much further evidence. In fact, this test proposed by Rhodin is virtually an " acceleration " test ; the general question of such tests is dealt with at a later stage in this report.

An interesting correspondence on the subject of the corrosion of Muntz metal appears in the *Engineer* for 1907, and though this report is not primarily concerned with this alloy, yet this correspondence is so important as bearing on the general question of the corrosion of copper-zinc alloys that a reference to it here is deemed advisable.

In Australian waters Muntz metal sheathing is largely used for protecting timber piles, &c., immersed in sea-water, from attack by the teredo. Such sheathing should have a very long life, and in actual practice it has been known to last from twenty to fifty years. In such cases the alloy is dissolved away quite uniformly, the copper and zinc appearing to pass into solution in the exact proportions in which they exist in the metal ; as a result the alloy will wear down to a sheet almost as thin as brown paper before actual perforation of the sheet occurs.

In recent years, however, considerable trouble has arisen owing to the fact that the effective life of the alloy has been very much shortened. Instead of dissolving uniformly, the zinc has passed into solution alone, or with but little copper. The result is that the alloy becomes quite brittle and useless. Hamlet states that a sample of Muntz metal (approximately 60 per cent. copper and 40 per cent. zinc) after a comparatively short period of immersion had the following composition :—

						Per Cent.
Copper	.	.	.	.	.	92·06
Zinc	.	.	.	.	.	7·42
Other metals	.	.	.	.	.	0·52

In a report to the Government of New South Wales on the deterioration of modern sheathing, Hamlet states his conclusions as to the causes of failure as follows :—

1. The presence in the alloy of masses of material differing

in chemical composition from the rest of the sheet. In consequence, voltaic couples are set up when the composite material is placed in sea-water.

2. The lack of sufficient metallic tin, which lack seriously interferes with the resisting power of the alloy against corrosion.

3. The use of too pure a copper, such as electrolytic copper, instead of that made by the old poling smelting process.

In a letter addressed to the editor of the *Engineer*, Sir Gerard Muntz discusses at length these conclusions, and his letter forms an important contribution to the study of corrosion, as it is the most detailed of the few available statements of the views held by actual manufacturers of this and similar alloys.

Sir Gerard Muntz states that the trouble of dezincifications first arose about the year 1898, and that, in consequence, an elaborate series of experiments has been carried out at his works to determine the cause. These experiments were superintended by Bertram Blount, who investigated the matter on behalf of the authorities in Australia, and subsequently continued his work on behalf of the Muntz Metal Co. These investigations showed :

" 1. That there was no alteration in the works practice, which was identical with that pursued during the past half-century, during which the sheathing had given entire satisfaction.

" 2. That the copper and zinc were present in the sheathing in the same proportions as formerly.

" 3. That the composition of the nails used in fixing the sheets was not responsible for the corrosion, since there was no apparent difference in various sheets with which nails of divergent alloys had been used.

" 4. That it did not appear that the deterioration was caused by earth currents resultant from electric lighting or power plants, as cases occasionally occurred far from such possibility.

" 5. That one cause of corrosion was the contact of the Muntz metal sheets with a backing of brown paper and varnish, which had been substituted for felt and Stockholm tar in recent years.

" 6. That another possible cause of corrosion was the ab-

sence from the copper used in recent years of certain small quantities of impurities, which, it was thought, might retard corrosion.

" 7. That electrolytic copper should not be used in the manufacture of Muntz metal."

Muntz concludes by repudiating entirely Hamlet's theory that corrosion can be due in any way to bad mixing of the copper and zinc in the course of manufacture. Nevertheless, there is no doubt that Hamlet's view has obtained credence amongst engineers, and even chemists. At first sight it appears a highly probable theory, and seems to gain support from the actual appearance of the tubes. The present author, as an entirely unbiassed observer, wishes to state that in his opinion, as far as Muntz metal and 70 : 30 brass are concerned, imperfect mixing of the copper and zinc is not a cause of the corrosion of alloys. No one who is familiar with the properties and methods of manufacture of these alloys will contradict this statement, and any doubts may be easily set at rest by an attempt to make an imperfectly mixed alloy by any reasonable method of preparation. In the case of condenser tubes, the present author has carried out an extended series of experiments on the variation of the percentage of zinc along 16 feet lengths purchased on the open market, and has come to the conclusion that the minute variations met with come within the experimental errors of the zinc determination.

With regard to Hamlet's other conclusions, Muntz states that he considers (2) may have some influence on corrosion, and that he accepts (3) as one cause of the trouble.

Lincoln [*] and his associates have published accounts of an interesting series of laboratory experiments on the corrosion of copper-zinc alloys. Thirteen specimens, to represent the whole series of brasses, were prepared and carefully annealed with the object of securing perfect uniformity of structure and condition of complete equilibrium. They were then submitted to the action of various salt solutions, including common salt and synthetic sea-water. The alloys were revolved at a speed of 800 revolutions per minute during the experiments, and the corrosion was hastened by the application of an external

electromotive force, which passed a current of 0·03 ampere through the solution. The cathodes were of platinum, and the experiments were carried on for six or seven hours. The corrosion products, consisting of any insoluble salts formed, and any material partially adherent to the corroding electrode, were analysed, and the total loss of weight of the electrode was also determined. The results obtained for sea-water are given in Fig. 2. The sea-water used was made up artificially in the laboratory, nearly according to Dittmar's formula, which is as follows :—

Total Solids 3·5 per Cent., made up as follows—

	Per Cent.
NaCl	77·75
$MgCl_2$	10·87
$MgSO_4$	4·73
$CuSO_4$	3·60
K_2SO_4	2·46
$MgBr_2$	0·21
$CuCO_3$	0·34

Lincoln modified this by putting in the whole of the carbonate as potassium carbonate, and the calcium as calcium sulphate. In any case the combination of acids and bases is an arbitrary one. The upper curves of the figures give the total loss of weight of the brass electrodes ; the lower curves the percentage of copper in the corrosion products. The following general consequences may be deduced :—

1. Under the given conditions copper is more corrodible than any of the brasses.

2. The rate of corrosion falls off quite gradually with increase of zinc till about 36 per cent. of zinc is reached.

3. When rather more zinc than this is present the corrosion falls off rapidly, till about 50 per cent. of zinc is reached.

4. A further increase in zinc does not alter the rate of corrosion.

5. With less than 36 per cent. of zinc the corrosion products have the same composition as the test piece ; with more than about 50 per cent. of zinc the corrosion product is pure zinc.

This series of experiments is interesting and important. If
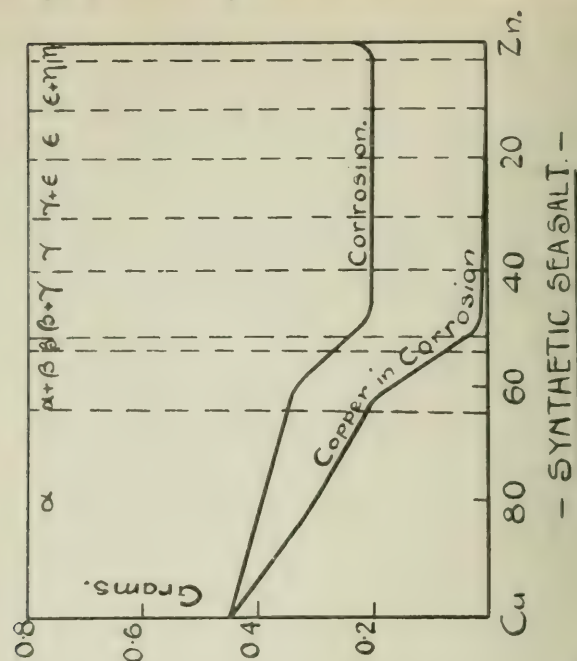
FIG. 2.
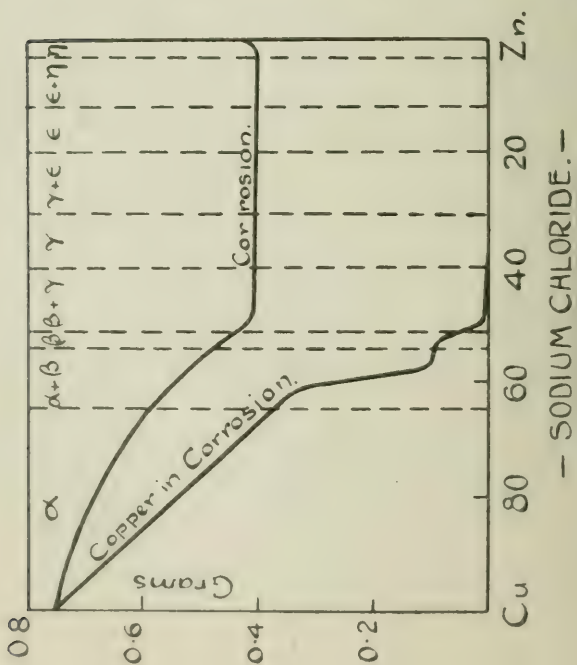
we take the case of 70 : 30 brass, *i.e.* the condenser tube alloy, we find that, under the conditions of Lincoln's experiments, it appears to corrode without undergoing any change of composition. In practice it is a fact familiar to most who have studied the matter that dezincification occurs to such an extent that in many cases it is obvious to the eye. This difference between the two sets of results is, in the author's opinion, to be attributed to several causes, and the following observations may perhaps serve to elucidate them.

When corrosion is rapid and penetrates deeply, as in Lincoln's experiment, and also in many practical cases of corrosion, the zinc probably passes into solution, and the copper is left behind as a comparatively loose deposit which can, with little trouble, be scraped off from the corroding brass. We may suppose that in Lincoln's experiment the zinc went into solution preferentially accompanied by little of the copper, and was subsequently precipitated as a basic salt. The copper would be left behind as a loosely adhering deposit; some of this would probably drop off into solution, and thus form part of the corrosion product. In addition to this, and especially in the case of Muntz metal and similar alloys, actual exfoliation, or falling out of comparatively unattacked crystals, owing to excessive corrosion of the metal which surrounded them, would probably take place. Lincoln also scraped all the loosely adhering material off his electrodes and added it to the corrosion products, and then analysed the whole material thus obtained. It is not remarkable, therefore, that his results should show practically the same ratio of copper to zinc in the corrosion product as occurred in the original metal.

Moreover, even if we admit that copper-rich brasses really corrode without change of composition when an external electromotive force is applied, it by no means follows that they will do so when it is not present. It is well known in the inverse problem, the deposition of brass from solution, that an increase in electromotive force tends to deposit the more electro-positive zinc in relatively greater proportion than electro-negative copper. Hence it is reasonable to assume that an increase of electromotive force will have the effect

of pushing the less electro-positive copper into solution to assist in carrying the current. Hence with an external electromotive force the relative corrosion will not be the same as without that electromotive force. Also, in Lincoln's experiments, which were carried out in small beakers containing only 200 cubic centimetres of solution, a considerable increase of zinc ions would occur during the experiment. Hence the osmotic pressure of zinc ions would increase and oppose the entrance of more zinc ions. The effect would be to increase relatively the number of copper ions passing into solution. For all these reasons, therefore, Lincoln's results must be used with caution. He also carried out a few tests on purely chemical corrosion with subsequent microscopic examination on α and β brasses. He showed that the β constituent only was attacked at first, leaving areas rich in copper, and not until this change had penetrated for some distance was the α attacked undergoing a similar change. It is a significant fact that in all the cases where no external electromotive force was used there was less copper in the corrosion product than in the test piece. It would seem, therefore, that Lincoln's main series of experiments have only an indirect bearing on the product problem, since here the practical danger is zincification.

Rhead [*] has published a paper on some probable causes of the corrosion of copper and brass, but it has been so recently and fully discussed by members of the Institute that no detailed consideration of it is necessary here.

Reference may also be made to a paper in the *Mechanical Engineer*,[†] and to one by C. J. Reed.[‡]

There are very few papers dealing primarily with the methods of preventing corrosion. Amongst the old workers Sir Humphry Davy, in 1824–5, paid some attention to the subject, and proposed to protect copper sheathing by means of a more electro-positive metal, such as zinc or iron. The final result of his researches was to show that the sheathing was perfectly protected when the ratio of its area to that of the

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[*] E. L. Rhead, *Journal of the Institute of Metals*, 1909, vol. ii. No. 2.
[†] *Mechanical Engineer*, October 22, 1909.
[‡] *Metallurgical and Chemical Engineering*, vol. vii. p. 316.

protecting metal was as great as a thousand to one. This method was tried for some time, but was abandoned owing to the rapid dissolution of the protecting metal, and to the fact that the sheathing, when protected, became still more loaded with sea-weeds and barnacles than when unprotected.

Diegel,[*] in 1898, again demonstrated experimentally the protective action of zinc and iron on copper and brass, and more recently Cohen has worked along similar lines, and reference has already been made to his work.

The practical difficulties of protection by means of a more electro-positive metal have been found to be very great, even in the case of sheathing, as has been stated above. They are equally great in the case of surface condensers using water flowing through the tubes, and they have, in consequence, not been universally adopted for this purpose.

Many attempts have been made to find a suitable coating to protect tubes and metallic fittings from contact with sea-water. On the one hand, non-metallic materials, such as varnishes, lacquer, asphalt, and special forms of cement, have been proposed. On the other hand, coatings of metals less susceptible to attack have been tried, and especially tin, lead, and tin-lead alloys. The drawback to all the coatings mentioned is that they either crack or scale off easily, or else they cannot be applied as continuous and unbroken surfaces, absolutely free from pin-holes and other small defects. If such defects exist they will, in many cases, have the effect of increasing the rate of corrosion.

Some interesting and novel experiments have been carried out by Utheman, a member of the Engineering Council of the German navy, and were described by him in *Le Génie Civil*.[†] He recognises the fact that contact with a more electropositive metal will protect copper and brass from corrosion, but that this protective influence does not extend far from the metal producing it. He proposes, therefore, to protect tubes by means of a spiral of iron wire wrapped round, or placed inside, the tube.

When such a combination is placed in sea-water the iron

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[*] *Marine Rundschau*, November 1898.

[†] *Le Genie Civil*, 1905; also *Journal of the American Society of Naval Engineers*, vol. xix. p. 3, and *Engineer*, 1907.

rapidly passes into solution and is oxidised, with formation of
some form of basic ferric oxide.   The copper or brass does not
dissolve and at first remains bright, but subsequently becomes
covered, between the spirals of iron, with a coating of the oxide
mentioned.   This coating soon becomes sufficiently adherent
to resist the mechanical action of a rapid current of water, and
completely protects the brass or copper tube from corrosion.
The coating is formed uniformly all over the tube, even under
the iron spiral itself.   The attack on the iron appears to cease
as soon as the coating is complete, and the iron spiral may
then be removed.   Utheman claims that only the particular
variety of iron oxide formed by the process described is protective.
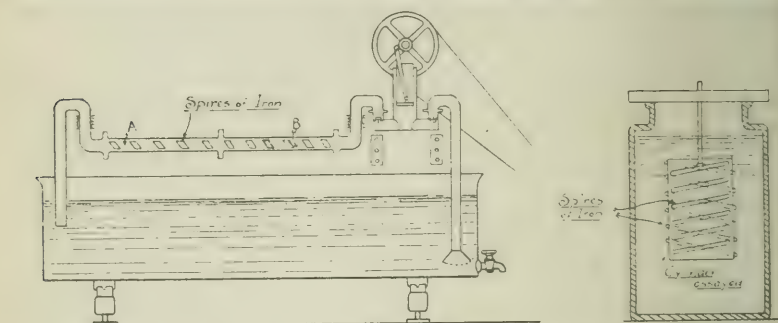
— ARRANGEMENTS ADOPTED FOR THE EXPERIMENTS WITH FLOWING WATER AND —
— WITH STAGNANT WATER. —

FIG. 3.

The oxide formed from metallic iron deposited electrolytically
on the interior of the tube was dissolved off by sea-water,
and consequently afforded no protection.   Utheman, referring
to his process, states : " This mode of protection is just as
properly applicable to the piping of bilge pumps, as the water
pumped by them is generally acid and strongly corrosive, and
to the channels of refrigerating apparatus, using a highly con-
centrated brine as the uncongealable liquid."

   The apparatus used by Utheman in conducting his experi-
ments is shown in Fig. 3.   A, B are two tubes being tested.
Water is circulated through them by an electrically driven
pump, which draws the sea-water from a reservoir situated
beneath the tubes, and delivers it into the same reservoir after

its passage through them. In the experiments the circulation was carried on for ten hours per day, and the water was allowed to remain stagnant in the tubes for the rest of the day. The tubes were cleaned, polished, and weighed before each experiment, and tests on protected and unprotected tubes were made simultaneously, so as to be strictly comparable. After the experiments the iron spiral was removed from the protected tube and then both were washed with water, alcohol, and benzine, and weighed. An increase in weight, due to deposition of oxide of iron, indicated protection. A decrease of weight indicated an attack on the copper and, therefore, lack of protection.

Experiments were also made on cylinders of copper or brass placed in still water, as shown in Fig. 3.

A separate series of experiments were carried out on condenser tubes with sea-water taken from the Gulf of Danzig and evaporated until it contained $3\frac{1}{2}$ per cent. of salt. The experiments were conducted at a temperature of 68° F. Table I. shows some results obtained by Utheman.

TABLE I.

I. *Flowing Water.*

Duration of Experiment in Hours.	Metal Used.	With or without Protection.	Alteration in Volume in Lbs. per Sq. Ft. of Metal Tested.	Condition.
94	Cast copper	With	$+0\cdot01702$	Water with 3·5 per cent. of sea salt. Temperature, 55·4° F.
94	,,	Without	$+0\cdot00198$	
187	Electro-copper	With	$+0\cdot03448$	Water with 3 per cent. of sea salt. Temperature, 64·4° F.
187	,,	Without	$-0\cdot02572$	

II. *Stagnant Water.*

74	Cast copper	With	$+0\cdot00100$	Sea-water containing 3·5 per cent. salts. Temperature, 71·6° F. Iron spirals on inside of cylinders only.
74	,,	Without	$-0\cdot02736$	
74	Brass	With	$+0\cdot00005$	
74	Commercial copper	Without	$-0\cdot02076$	
74	Condenser tube *	With	$+0\cdot00193$	Sea-water containing 3·5 per cent. salts. Temperature, 71·6° F. Iron spirals on both the inside and the outside.
74	Brass	With	$+0\cdot00088$	
74	Heckman bronze	Without	$-0\cdot02445$	
74	Brass	Without	$-0\cdot01476$	

* Of Heckman bronze.

Chief Engineer Isherwood. United States navy, commenting on Utheman's work, says: " As all the other processes which have been tried for this purpose (the protection of condenser tubes from corrosion) have been failures more or less signal, an entirely new one, supported by extensive experimental results. has great interest in steam engineering. and even if it should not prove to be practicable itself on a commercial scale, it may be valuable as a stepping-stone to something that will be commercially successful in a very important engineering subject. The process in question. and its results under the experimental conditions. of course. could not be accepted as a finality until tested for a considerable length of time on the large scale and under the conditions of actual practice." He adds, as the results of his own experiments. the following general conclusions on the subject of corrosion :—

" 1. Brass is more corroded when there is relative motion between the metal and liquid. than when there is no such motion." *Cf.* Sexton, above.

" 2. The larger the mass of metal exposed to corrosion, other things equal. the smaller will be the rate of its corrosion ; that is to say. a less absolute weight of metal would be destroyed the greater its mass.   In the case of condenser tubes, or of the metal sheathing of wooden ships, the thicker the metal the slower will be the rate of its corrosion, and not only relatively but absolutely.   As regards the condenser tubes, the thickening of their metal involves. not only increased money cost at first. but increased weight to be permanently carried afterwards, and somewhat increased dimensions of the condenser.   This money lost at first. however, is recouped at last by the greater durability of the tubes above the proportionality of the increased weight, leaving out of consideration the valuable convenience of their longer endurance, which is a merit of importance. especially for naval steamers.   The thickness now used for the metal of the tubes should be doubled.

" 3. Coating the tubes with tin delays their corrosion as long as the tin lasts, but its durability is not great. and its very slight thickness on the tubes cannot be increased beyond what is obtained from the first dip. . . . Nevertheless. this 'tinning' should never be omitted, although it involves

additional surface of tubes for equal heat conduction in equal time.

" 4. The corrosion of condenser tubes is principally on the sea-water side, but the distilled water side also suffers much, the corroding agents being the atmospheric gases mingled with the steam. This corrosion is quite uniform compared with the corrosion on the sea-water side, and the resulting oxides and salts are often carried into the boiler with the feed water and produce injurious effects upon the iron.

5. " The surface condenser should be opened at intervals— say of six months ; its tubes drawn out, cleaned, and examined, with the particular view of ascertaining if any holes have been corroded through them by means of which the sea-water could find entrance into the distilled water place."

As regards the method of protection advised by Utheman, the present author has not been able to find any description of experiments carried out on the practical scale. Whether this is to be attributed to insufficient search, or to the fact that serious difficulties have been encountered during preliminary trials on a larger scale, and that consequently publication has been withheld, or to a distrust of the process on the part of the engineers, or to other causes, is not clear, and the author would welcome information on the subject from any one who has had actual experience with this process, which was originally proposed in the year 1905.

SECTION III.

Synopsis of the Views of the Authors of the Foregoing Papers.

A detailed study of the papers that have just been considered will show that, almost without exception, the authors attribute the corrosive action of sea-water to electrolytic action. They are, however, not unanimous in their selection of the electro-negative member of the voltaic couple. Further, their views are in some other respects mutually contradictory, or are irreconcilable with the conclusions of authors not hitherto mentioned. For instance, Tilden con-

siders that deposits of basic chloride will enhance corrosion, and recommends that precautions be taken to prevent its accumulation; Sexton, on the other hand, considers that this material is, if anything, slightly protective. Cohen states that CuO is an excellent protector owing to its insolubility in sea-water; Charpy * considers that it is the primary product formed in the action of sea-water on copper. The present author, on this point, is entirely in accord with Cohen. Diegel considers that nickel retards the corrosion of brasses; Rhodin, that it accelerates the attack. Other mutually contradictory statements may be found in the papers already noticed, as well as in others on the subject.

On the other hand, there is a general agreement between Tilden, Milton and Larke, Hamlet and others, that the presence of Cu_2O is harmful. Sexton, Muntz, and others suggest that carbon particles, ashes, and other impurities, not necessarily derived from the tubes themselves, are serious and frequent causes of trouble. Since Arnold first employed the microscope in the study of corrosion it has been much used for the purpose of detecting such impurities in the alloys, and a good deal of work has been done to discover possible external sources of electro-negative material which might be introduced into corroded tubes or pipes.

Nevertheless, it appears to the present author that even this aspect of the subject—the aspect which has received most attention—has been but incompletely studied. In some cases the authors have omitted to ascertain whether the impurity impugned does or does not conduct electricity. If it does not it cannot form an electro-negative node—*i.e.* it cannot set up electrolytic action. The disputed question of the effect of basic chloride can be settled by a determination of its electric conductivity. If this be very slight, the resistance of the circuit will be too great for the small electromotive force set up between the positive and negative nodes to send round it a current sufficiently intense to be practically harmful. The same remarks apply to the action of Cu_2O and ashes. Non-conductors may, however, act as " depolarisers," and this aspect of the question is dealt with further on in this report.

* *Chemie Minerale*, Moissan; article " Cuivre," by G. Charpy, 1906.

With regard to the means of preventing corrosion, there seems to be a fair degree of agreement on certain points amongst the authors. The means generally approved are the two following :—

1. The tubes should be kept free from any solid deposit by cleaning at frequent intervals (Tilden, Stewart, Sexton).

2. A protective coating of tin or other suitable substances should be used (Cohen, Utheman, Isherwood).

Other means less generally considered to be effective are :—

3. The access of stray currents to the tubes should be prevented (Milton and Larke, Sinclair *).

4. The use of olive oil should be abandoned (Stewart).

The exceedingly laborious nature of the task of cleaning out the hundreds or even thousands of tubes that form a battery of condensers has prevented the wide adoption of precaution (1). In the case of the last three precautions opinion is not quite unanimous. It may be pointed out that Sexton doubts the value of tin used either in the alloy or as a surface coating ; also that Stewart does not think stray currents can be the cause of corrosion ; and that Milton did not believe that olive oil caused the corrosion of copper in the steamers examined by Stewart.

An examination of the literature of corrosion has thus served to show that the ideas prevailing in the minds of many of the investigators and writers on the subject have been very contradictory ; also that there is a prevalent idea that the term " corrosion " includes under one heading several quite distinct classes of phenomena which are not necessarily related to one another at all closely.

A common classification is as follows :—

(a) *Chemical Action.*—This is supposed to be the process by which a simple metal, such as zinc, dissolves in an acid.

(b) A combined attack by a corrosive liquid and the atmosphere, such as occurs when brass is attacked at the water-level by sea-water. The oxygen of the atmosphere is supposed to be responsible for a

* *Journal of the Institute of Metals*, 1909, vol. ii., discussion on Rhead's paper.

primary attack on the metal. Thus Charpy [*]
gives the following series of reaction as represent-
ing the action of sea-water on copper :

$$4Cu + 2O_2 \qquad\qquad = 4CuO$$
$$4CuO + 2NaCl + CO_2 + 3H_2O = Na_2CO_3 + (3CuO, CuCl_2, 3H_2O)$$
$$3CuO, CuCl_2, 3H_2O + 4Cu \quad = Cu_2Cl_2 + 3Cu_2O + 3H_2O$$
$$\dagger\, 3Cu_2Cl_2 + 3O + 3H_2O \qquad - (3CuO, CuCl_2, 3H_2O)$$
$$CuCl_2 + 3Cu + 3O + 3H_2O \quad = 3CuO, CuCl_2 . 3H_2O$$
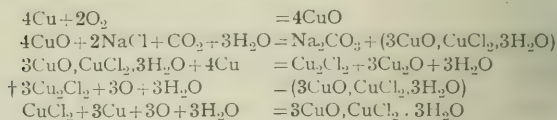
(*c*) *Electro-Chemical Corrosion.*—In nearly all cases this is
considered to be a phenomenon quite distinct from
the other two.

The author has no hesitation in stating that the balance
of evidence clearly shows that the primary process of the
corrosion of any metal or alloy is, in all three cases, identical,
and consists of the entrance of the metals into the solution as
ions. In the last two cases, it is true that the *speed* of the
action is affected in various ways, but the difference between
these and the first case is quantitative rather than qualitative.
Thus in Class B, the presence of carbon dioxide in the water will
not only increase the *rate* at which zinc will pass into solution
owing to the presence of an increased number of H ions, but
the presence of carbon dioxide and oxygen will also enable
copper to displace hydrogen from solution and afterwards to
be itself removed from solution as insoluble basic chloride.
The whole corrosive action is thus speeded up (by catalytic
action or otherwise), and at the same time made more evident
to the eye, owing to the formation of the salts mentioned ; but
it does not differ essentially from the phenomena included
under Class A.

In the case of Class C, the effect of the application of an
external electromotive force is merely to push both metals
rapidly into solution at the anode ; in fact, the electromotive
force reinforces the solution pressure of the metal. These
statements will be more clearly understood after a study of
Section IV. of this report.

The present author considers that enough has been said to

[*] Charpy, *Moissan's Traite de Chemie Minerale*, vol. v. p. 11, ed. 1906.

[†] A figure 3 seems to have been dropped from the right-hand side of this equation. No
emendation has been made in copying it from Charpy's article.

show that modern knowledge of the corrosion of copper and brass is in a somewhat confused and tangled state, and that very few positive experimental results can be considered as thoroughly established. He believes this to be due to the fact that the mechanism of the solution of the metal or alloy has not been sufficiently taken into account. He considers it necessary, therefore, that the whole case should be restated from the point of view of the ionic theory of solutions. It is not here claimed that this theory will for all time remain unchanged. As new facts are from time to time discovered, some modifications will probably have to be made—our standpoint will have to be shifted slightly—but at the present time there is little doubt but that this theory presents the best general view of all the facts now known, and it has been adopted throughout the rest of this report.

A somewhat detailed statement of the theory will now be made.

SECTION IV.

THE ELECTROLYTIC THEORY OF CORROSION.

It may safely be assumed that all metals and alloys when plunged into dilute acids or into water, either pure or containing salts in solution, tend to pass into solution. This tendency is known as the solution pressure of the metal, and for any particular solvent is a constant which depends only on the temperature. When a metal passes into solution in a solvent, certain molecules or atoms tend to separate themselves from the body of the metal and distribute themselves, in the form of ions, uniformly throughout the solvent. Ions are atoms or groups of atoms carrying very large charges of static electricity.* The solvent, as well as the substance passing into solution, may be more or less dissociated into ions. Thus ordinary water is dissociated to a limited extent into hydrogen ions and (OH) ions, the latter being known as hydroxyl ions. Many acids in solution are highly dissociated,

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* Many concepts of the ionic theory of solutions are here stated dogmatically. Their justification, experimental and theoretical, can be found in modern text-books of physical chemistry.

and are characterised by the presence of H ions: bases in solution are also dissociated and are characterised by hydroxyl ions. The metallic and hydrogen ions carry positive charges and are called cations; hydroxyl ions. Cl, Br, and the acid radicles carry negative charges and are called anions.

Acids and solutions of metallic salts conduct electric currents electrically, that is by the movement of ions. When insoluble electrodes are connected externally to positive and negative sources of electricity and are plunged into an electrolyte, the positively charged ions (cations), which have hitherto been pursuing haphazard paths between the molecules of solvent, begin at once to move in the direction of the current, and sooner or later arrive at the cathode, that is, the positive electrode; hence the name cations or down-streamers. Arrived at the cathode they give up their positive charges to the electrode and return to the molecular condition, in which we are ordinarily acquainted with them. The anions carry negative charges and travel towards the negative pole, and there give up their negative charges, hence their name anions, or up-streamers. The passage of the current is thus effected by the simultaneous passage of positive and negative charges to the electrodes. Cations are generally denominated by their chemical symbols with a dot over them; anions have instead a dash: thus

$$Zn \rightarrow Zn^{..} \; or \; Zn + 2\oplus \rightarrow Zn^{..}$$
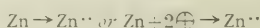
means that zinc is passing into the ionic condition, and

$$Cl_2 \rightarrow 2Cl'$$

means that a molecule of chlorine is being broken up into two chlorine ions. It should be noticed that chlorine, which is monovalent, forms ions carrying unit negative charges, denominated by one dash. Zinc, which is divalent, carries two positive charges, and this is denoted by two dots. The general rule is that monovalent elements or groups carry unit charges on each ion, e.g. $Na^{.}$, $H^{.}$, $(NO_3)'$: divalent elements two charges, and trivalent elements three charges.

Now consider the case of common salt placed in pure water at the ordinary temperature. Owing to its solution pressure, which salts exhibit in common with metals and alloys, it will

tend to pass into solution, for the most part breaking up as it does so into Na ions, Cl ions.* The process of solution will continue till a certain concentration has been reached, *i.e.* until unit volume of solution contains a certain definite number Na ions. The solution is then termed saturated, and the process of solution apparently stops. The explanation of this is as follows : as soon as there are any ions at all in solution they assume a certain tendency to pass out of solution and deposit themselves on the undissolved salt. As long as there are but a few of them in solution, this action will be overcome by the solution pressure, that is by the tendency for undissolved salt to pass into solution in the ionic form. But as the concentration of Na ions in solution increases, the tendency of dissolved ions to pass out of solution will gradually increase. Finally the two tendencies will exactly balance one another, and a condition of equilibrium will result. The tendency which opposes solution pressure, and finally balances it, is termed osmotic pressure. It is a real pressure of very considerable magnitude exerted by the ions already in solution, and opposing the entry into the solution of more ions. It is comparable to the pressure exerted by a gas on the walls of the containing vessel.

The osmotic pressure of a solution, then, depends on the concentration of the ions in solution. It opposes solution pressure and finally balances it when a certain definite ionic concentration has been reached. Osmotic pressure is only felt in the interior of liquids, and not at all at their free surfaces. This arises from the fact that it is there opposed by a still greater pressure, known as surface tension, which acts towards the interior of a liquid and consequently in opposition to osmotic pressure.

Now in the case of a salt in contact with its solution, if the ionic concentration is low, salt will pass into solution : if, on the other hand, the concentration is higher than the normal value, salt will separate out. In either case a state of equilibrium will be reached, *i.e.* the solution pressure and the osmotic pressure will exactly balance one another.

<div align="center">Solution pressure ⇌ osmotic pressure.</div>

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* But some whole molecules, undissociated, will also pass into solution.

Take, now, the case of a metal, such as zinc, plunged into a solution of one of its salts. As in the case of common salt, zinc will tend to pass into solution; but instead of sending out both positive and negative ions, *e.g.* Na· and Cl′ ions, which would keep the solution electrically neutral, it can only send out positive Zn ions. The result of this will be that the solution will not remain electrically neutral, but will become positively charged, owing to the presence of excess of positive zinc ions.

The zinc electrode, since it is sending out ions carrying positive charges, will become negatively charged. A difference of potential will thus be set up between the electrode and solution. The result will be an electrostatic tension between electrode and solution which will hold the ions in solution in the neighbourhood of the electrode. The tension, in conjunction with the osmotic pressure, will very soon balance the solution pressure of the zinc. This will occur when a very few ions have passed into solution, and consequently no more zinc will dissolve. The difference of potential between the metal and solution is known as the electrode potential of the metal. It gives rise to what is known as an electrical double layer. This consists of negative charges on the electrode and a number of positively charged ions which are held by the tension in the immediate neighbourhood of the electrode. It is formed when an extremely minute quantity of metal has passed into solution, and there is, consequently, no apparent change when a metal is placed in a solution of one of its salts. The result may be expressed thus:—

Solution pressure $\leftarrow\rightarrow$ electrostatic tension + osmotic pressure.

The electrode potential, which is the measure of the electrostatic tension of a metal plunged into a solution of one of its salts, is seen to be an electromotive force set up at the surface of contact of metal and solution. Its value is different for different metals. It is dependent on the concentration of ions in solution and also on the temperature. The relative values have been measured for a large number of metals in normal solutions of their salts, and absolute values have also

been obtained by comparison with an electrode of supposed zero potential. Solution pressures may be calculated from the electrode potential by the formula—

$$E = 0.058 \log \frac{P}{p}$$

at 17° C., where E is the electrode potential, P the solution tension of the metal in question, and p the osmotic pressure of its ions in solution.

It has been already stated that a zinc atom passing into solution acquires a positive charge and becomes an ion. The question then arises, Whence does this charge come? Ordinarily it comes from the mass of the electrode and leaves it negatively charged, as has been already indicated. Now imagine a piece of zinc placed in a solution containing copper ions. Owing to its solution pressure the zinc will at once begin to send off ions into the solution, which will become positively charged. The mass of zinc will then be negatively charged. A double layer would soon be formed and stop further solution of the zinc but for the presence of copper ions in the solution. Since the latter contains an excess of positive ions, and since the copper ions have a low solution pressure, these will readily give up their charges to the negatively charged zinc and plate out as metallic copper.* Thus zinc will displace copper from solution; the experimental result is familiar to all, its mechanism is not so well known.

Now by a series of similar displacement experiments metals may be arranged in a series which will indicate the order in which they will turn each other out of a given solution. This series will also, with some exceptions, represent the order of the electrode potentials and the solution pressures of the metals. Hydrogen may be regarded as a metal and included in the series. Such a series of the common metals is given below. It refers to the electromotive force developed at a metallic electrode when placed in a normal solution of one of its salts at 0° C. Any member of the series is said to be electro-positive to any other occurring below it in the list; similarly, any substance is said to be electro-negative to any other occurring above it.

* In a normal solution, copper ions leave the solution and deposit copper even on metallic copper.

E

*Table of Electrode Potentials (at 0° C.).**

$Zn^{..} + 0\cdot493$	$H^{.} - 0\cdot277$
$Fe^{..} + 0\cdot063$	$Cu^{..} - 0\cdot606$
$Ni^{..} + 0\cdot049$	$O'' - 1\cdot396$
$Pb - 0\cdot129$	$Cl' - 1\cdot694$

The values given refer to normal solutions. If, now, a more dilute solution than this be substituted the osmotic pressure of ions in solution will be lowered; and since

Solution pressure $\overrightarrow{\underleftarrow{}}$ electrode potential + osmotic pressure,

it is evident that the electrode potential must be raised.

To take an actual case, the electrode potential of copper in normal solution is $0\cdot606$ volts; in decinormal solution $0\cdot606 + \dfrac{0\cdot058}{n}$ where n is the valency.

Now the electrode potential developed at the surface of contact of a corrodible metallic electrode with a solution of one of its salts is the driving power of the current in most primary cells. Taking the case of a Daniell cell, we have a copper electrode in the solution of copper sulphate separated by a porous division from a zinc electrode in a solution of zinc sulphate. The porous pot is merely to prevent too rapid diffusion of the two solutions into one another. The electrode potentials of zinc and copper in a normal solution of their salts will be seen to be $+ 0\cdot5$ and $- 0\cdot6$, or a *difference* of $1\cdot1$ volts. If the two electrodes be connected together by a conductor the following series of reactions will take place:—

1. Zinc, being strongly electro-positive, will pass into solution in the ionic form, carrying positive charges with it, *i.e.* a current will tend to flow from zinc to solution. The zinc electrode will be negatively charged, and very soon a double layer will be set up.

2. Copper, being electro-negative, and placed in a saturated solution of its salt, its ions will tend to pass out of solution and become deposited on the cathode. They will there give up their positive charges to the electrode, *i.e.* a current will tend to pass from solution to electrode.

3. This electrode will be the positive electrode of the cell

* Wilsmore and Ostwald; *Zeitschrift für physikalische Chemie*, 1901, vol. xxxvi. p. 92.

The charges given up to it will be carried along the conductor to the zinc, or negative pole, there to neutralise the negative charges arising from the loss of positively charged zinc ions. Hence the double layer formed on the surface of the zinc will be destroyed and more zinc will pass into solution.

The action will proceed as long as an external conductor connects the two poles. When they are disconnected the action will be discontinued by reason of the formation of electrolytic double layers at the two poles; thus at the copper electrode the positive charge will repel positively charged copper ions, which will now no longer pass out of solution.

We are now in a position to gather a few fundamental ideas on the subject of corrosion. First of all, it is most important to notice that the corrosion of a metal, usually zinc, is the essential feature of most primary cells. Solution of the zinc does not take place because of the galvanic current set up between, say, the copper and zinc of a Daniell cell. It is more nearly correct to put the matter the other way round and to say that the solution or corrosion of the zinc is the cause of the current. A primary cell is simply an arrangement for transforming the chemical energy of the zinc into the electrical energy of a current. Similarly a dynamo driven by a steam-engine is merely a cumbrous arrangement for converting the chemical energy of the coal into the electrical energy of a current. The source of this energy is the combustion, *i.e.* the rapid corrosion of the coal. Similarly, in the first case, if no zinc corrosion passes in solution, no current results.

Now the possibility of a metal corroding or passing into solution to any considerable extent when placed in a given liquid is dependent upon whether it can take positive charges from that liquid in any way. If it cannot, any ions passing into the solution must abstract them from the metal itself, and an electrolytic double layer will be formed which will stop further solution, as has already been indicated. Now there are the following possible methods of obtaining positive charges from a solvent:—

1. The removal of positive ions from solution.
2. The destruction of positive ions in solution.
3. The production of negative ions in solution.

For the present we need only concern ourselves with the first of these sources, since it is the most important. From what has been already stated, it is clear that if there are present in the liquid positive ions of a less electro-positive nature than the metal we are dealing with, then these will be replaced by ions of that metal. Hence, in general, the solution or corrosion of a metal by a liquid is conditioned by the presence in that liquid of ions of a less electro-positive nature. If there be many such ions, corrosion will be rapid; if few, corrosion will be slow. This may be said to be the general rule; exceptions may occur, and these will be dealt with later.

The question now arises, How will an applied external electromotive force affect the rate of corrosion? Obviously it will act mainly by hastening the removal of positively charged ions from solution, and so enabling more electro-positive ions to replace them. If this be borne clearly in mind it will clear up much of the confusion of thought in connection with the corrosion problem which is apparent in much of the literature on the subject. It may be here noted that the direction of the applied electromotive force is of great importance. Due to it, a current will flow through the electrolyte, and at the place where the current enters the electrolyte solution or corrosion will take place, since positive charges are entering the liquid. The area from which it leaves the electrolyte will be to some extent protected from corrosion, since here positive charges are leaving the electrolyte. The practical application of these statements will be dealt with shortly.

It has already been stated that the electrode potential of a metal in a given solution is a constant of the metal, depending only on the temperature and concentration. If the concentration be increased the potential will decrease; if the concentration be decreased the potential will increase. In the light of these facts let us consider the conditions favourable for the replacement of a metal A from solution by metal B.

Suppose the concentration of B be very low, *i.e.* its osmotic pressure be very low. Then since

$$\text{Solution pressure} \rightleftharpoons \text{electrostatic tension} + \text{osmotic pressure},$$

a considerable number of ions will pass into solution carrying

positive charges, and will form a double layer. Now if the concentration of the A ions is high in the solution, which now contains an excess of positive ions, some A ions will be certain to approach metal B and give up to it their positive charges, thus neutralising part of its negative charge. When this happens a corresponding number of B ions will be freed from the double layer, and will act as ions do normally in a solution. Now the more A ions there are in solution to start with the more rapidly this action will proceed. Hence the conditions sought for are that the initial concentration of A should be high and of B low in the original solution. Now if the concentration of B be sufficiently low and the concentration of A sufficiently high, considered relatively to that of B, then B may replace A even if in normal solutions A is more electro-positive than B. The deduction to be drawn is that the replacement of one metal by another may sometimes be determined by the ratios of ionic concentrations.

Let us now consider the case of pure metal plunged into pure water, and purity for our present purpose is to be ideal chemical purity—a purity altogether unattainable by any methods of preparation at present available. The metal, moreover, is to be considered as absolutely free from physical strain. It is to be perfectly homogeneous, chemically and physically. Such a metal, unless it decomposes water, as does sodium for instance, must necessarily be insoluble, and this will be true, no matter what the solution tension of the metal may be. In each case the solution tension, however high its value, will be counterbalanced by the electro-static tension of the double layer which will be formed all over the metal. Chemical tests on the water for the metal will give blank results, for the number of ions carrying positive charges which have passed into solution to form the double layer are generally too few in number to be detected by any method at present known to chemistry. If the water be replaced by pure acids the same result will be obtained.

Now such a metal as that described does not exist.[*] It is

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[*] Lambert and Thomson (*Proceedings of the Chemical Society*, 1910, vol. xxvi. p. 377) have shown quite recently that iron can be prepared in a state of such purity that when exposed to water and ordinary air no oxidation took place, *i.e.* no free iron passed into solution.

well known that iron and steel readily pass into solution in any ordinary sample of water and quite rapidly in dilute acids. Copper and zinc are also acted on by dilute acids, sea-water, and many other solvents.   How is it, then, that the formation of a double layer does not protect them in ordinary cases? The answer is obviously that metals, as ordinarily prepared, are not homogeneous, either chemically or physically, and the consequence is that the double layers are not formed.

We will first consider the case of chemical impurities.   If a small quantity of a second element be added to our pure metal it will not, in general, be distributed perfectly uniformly in the resulting solid alloy.   As examples, the irregular distribution of lead, copper oxide, and arsenide in metallic copper may be cited.   In the case of steel, much work has been done to ascertain the exact distribution of the impurities, and it has been shown that the distribution is far from uniform.   In the case of the alloys which consist of a single solid solution, and which might be expected to be exceptionally uniform, we may get the cast structure, so well known in the case of brass or bronze, and which a microscope of even moderate power will show to be far from uniform.   In these cases a drastic annealing is required to secure anything like uniformity of chemical composition.   In view, too, of the fact that zinc is preferentially dissolved out of 70 : 30 brass by certain solvents, it is doubtful whether even annealing renders such a solid solution homogeneous to corrosive reagents.   It has been already suggested in a paper read before this Institute * that chemical compounds preserve their identity in solid solution, at least to some extent, and if this be so the solution cannot be minutely homogeneous.   In the case of castings made commercially on a large scale, such as those used for the production of condenser tubes, the metal may contain inclusions which will be mechanically driven in during the drawing process ; such inclusions may, for instance, be derived from the core of the mould and consist of carbon.†   In these, and many other ways, a commercial metallic product is certain to differ considerably from perfect homogeneity.

* Bengough and Hill, *Journal of the Institute of Metals*, 1910, vol. iii. No. 1, p. 63.

† See discussion by Sir Gerard Muntz on Rhead's paper, *Journal of the Institute of Metals*, 1909, vol. ii. No. 2.

It is almost equally certain to depart from perfect physical uniformity. Some parts may be worked or strained slightly more than others, either by hammering, drawing, or even by unequal distribution of contraction strains resulting from the shape of the casting; unequal speeds of cooling and local chilling will have similar results.*

All these cases of lack of uniformity, and many others that will readily occur to all who have to handle large quantities of metal on the commercial scale, are predisposing causes of corrosion. For the present purpose, however, it will be sufficient to select one and consider how it functions in this way. A very simple case will be that of zinc with a minute inclusion of carbon, and we will suppose the metal to be placed in a very dilute acid. Carbon has a very low solution pressure and electrode potential, and on this account forms the positive pole of most primary cells. Relatively to it zinc will be strongly electro-positive. A difference of potential will consequently be set up between the zinc and the carbon when they are placed together in the liquid. The zinc will pass into solution at points surrounding the carbon particle. The zinc will thus be negatively charged and the solution positively. The solution will then contain an excess of positive ions and a double layer will be formed round it. Consequently the hydrogen ions already in solution will be pushed out of solution at the cathode, that is, at the carbon particle, and will there give up their positive charges and assume the gaseous form. The carbon particle will thus be charged positively. Now when so charged it would give rise to a double layer in which the solution will be negatively charged, owing to the presence of excess of negatively charged Cl ions. Solution of the zinc would then cease but for the fact that the positive charge on the carbon particle and the negative charge on the zinc are in electrical communication through a conductor. Hence a current will flow from the carbon to the locality where the zinc is dissolving through the mass of the zinc itself. The charges at the electrodes will thus neutralise each other, the double layers will be broken down, and solution will proceed.

* Especially in the case of 70 : 30 brass. See Carpenter, *loc. cit.*

While fully recognising the importance of merely apparent uniformity of chemical state, which has, indeed, been pointed out by many writers, the author is inclined to think that the recognition which this phase of the subject has received has concentrated attention upon it too exclusively. That other and hitherto unidentified causes are at work and may be even more important is evident. Otherwise Muntz metal—a two-phase system—would always be much more rapidly corroded than say 70 : 30 brass, whereas Tilden and others have shown that this is not by any means always the case.

Turning now to the case of a metal which is not physically uniform, it will be sufficient to state that the balance of evidence now available appears to indicate that strained areas in a metal or alloy are electro-positive to unstrained areas. These strained areas will dissolve or corrode preferentially in exactly the same way as in our preliminary example given above. A valuable paper by Burgess [*] gives an admirable review of the experimental work carried out on the difference of potentials existing between strained and unstrained portions of metal, and those who are interested in this matter should refer to his paper, since space does not permit of any detailed account of work which has been done on this subject to be given here.

We shall henceforward assume that any portion of a metal or alloy which has been strained beyond its elastic limit is electro-positive to areas on the same specimens that have not been so strained. Now it is necessary to point out here that a number of speakers and writers on this subject seem to have scarcely appreciated the delicacy of the phenomena now under consideration. Some of the earlier workers on corrosion of steel have made elaborate investigations directed to ascertain quantitatively the difference of potential between the strained and unstrained parts of specimens of steel. On the other hand, there appear in the literature of the subject accounts of experiments, from the results of which deductions have been drawn in a directly opposite sense, and doubts have been expressed as to whether any such differences of potentials exist at all. In some cases quite insufficient care has been taken to remove the slight traces of grease resulting from

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[*] *Transactions of the American Electro-chemical Society*, 1908, vol. xiii. p. 17.

handling the specimens experimented with, and to secure that the surface of the specimen received precisely identical treatment in all respects before comparisons were made. Even with the most detailed precautions, however, it is not likely that any useful quantitative results would have been obtained. In the case of iron and steel, this matter has been summed up by Cushman and Gardner * as follows :—

" The apparently contradictory results arrived at by different experimenters may be best explained by the extreme delicacy of the equilibrium which governs the polarity. That iron has a definite solution pressure, has already been shown. If for any reason, however obscure, the solution tension is to any extent greater at one point on a given surface than at another, that point will be to some extent electro-positive to the other. Whether these points retain the polarity or whether it is actually reversed, depends on the nature of the given case, in which determinative influences may be at work which it is impossible to predicate."

The author entirely concurs in this statement. Any difference in the physical state between two points on a metal or alloy will probably be associated with a difference in electrode potential and solution pressure between those points. It is of secondary importance which point is positive and which negative. It must be carefully borne in mind that the difference may be merely a surface condition, and that when a few molecules have gone into solution from the surface of the more electro-positive points, the difference may cease, or may exist in the opposite sense. This part of the corrosion problem probably cannot be usefully attacked in a quantitative manner with our present experimental resources.

This portion of the report may be briefly summarised as follows :—

(1) Every metal and alloy has a definite and characteristic solution pressure in a given solvent ; this pressure depends only on the temperature and the concentration of its own metallic ion or ions in solution.

(2) Perfectly pure homogeneous metals are, notwithstanding this statement, practically insoluble owing to the formation of the electrolytic double layers.

* " Corrosion and Preservation of Iron and Steel," 1910 edition.

(3) Ordinary metals dissolve, or are corroded, owing to the fact that they are not chemically and physically homogeneous.

(4) Metals and alloys may be arranged in a definite order in which they will displace each other from normal solutions to their salts. This order is also that of the electrode potentials of the metals.

(5) Metal ions in solution exert a definite osmotic pressure, which opposes solution pressure, and so tends to prevent the entrance of more ions into solution.

(6) In general, a metal or alloy will be corroded by a solution which contains ions of a less electro-positive nature than that of the metal or alloy in question.

(7) Sometimes the ratios of the concentration of the ions in solution, that is ratios of the osmotic pressures, will determine whether or not a metal A will displace a metal B from solution.

We may deduce from the above:—

(8) When the corroding metal is displacing hydrogen from solution, the action will be accelerated by the presence of a " depolariser," *i.e.* some substance which will rapidly remove, by oxidation or other means, the displaced hydrogen. Such a depolariser may be present in the corroding liquid, or in the corroded metal.

(9) The nature of the surface of the metal may influence the speed of corrosion. If the surface be of such a nature as to facilitate the formation and removal of hydrogen gas, it will also facilitate corrosion.

SECTION V.

RESTATEMENT OF THE PROBLEM OF CORROSION—AUTHOR'S VIEWS OF THE PROBLEMS INVOLVED.

It now becomes necessary to consider more in detail the action of water, acids, and salt solutions on metallic copper. Carnelly [*] has shown that copper is soluble, to a minute

* *Journal of the Chemical Society*, 1876, vol. ii. p. 1.

extent, even in distilled water if oxygen be present. Now distilled water is dissociated into (H)· and (OH)′ only to a very slight extent; yet Carnelly's result shows that copper can replace some of the H ions it contains. Copper and hydrogen are next one another in the electrode potential series, but copper is the *less* electro-positive; Carnelly's result, therefore, is unexpected. It is, however, supported indirectly by other experimental evidence. Thus, Tilden * has shown that both dilute and strong HCl will react with copper with evolution of hydrogen. Dilute nitric and sulphuric acids also attack copper. The action of sea-water is quite rapid, and only too well known. (In this connection it may be mentioned that Tilden has shown that magnesium chloride, which is frequently regarded as very active in promoting the attack on copper, is much less harmful than sodium chloride.) Cohen and others have shown, however, that copper is only attacked by sea-water in the presence of air. The present author and others have found that air is also necessary to the action of acids on copper. Carnelly has examined the action of a large number of salt solutions, and has shown that solutions of sodium and potassium chloride, which readily absorb oxygen, are more active in dissolving copper than other chloride solutions. Much work has been done to explain the mechanism of these reactions, and the matter is summed up by Donnan † as follows :—When an atom of copper passes into solution it must obtain one or two positive charges, according as it passes into solution as cuprous or cupric ion. Alternatively, one or two negative charges may appear, which comes to the same thing. Now in salt solutions, such as sea-water, the cations with the least solution pressure are the hydrogen ions; hence, if copper is to pass into solution, it must displace hydrogen. From quite pure salt solutions copper cannot displace hydrogen; but if there be present in the solution some depolariser which will remove the hydrogen by oxidation sufficiently quickly at the moment it is about to be discharged, then the copper can replace hydrogen. The

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* Tilden, *loc. cit.*
† Abegg's *Handbuch der Anorganische Chemie*, 1908, article " Kupfer."

depolariser in the case of sea-water is oxygen, and the reactions, according to Traube,* are as follows :—

$$Cu + 2\oplus \longrightarrow Cu\cdot\cdot$$
$$H_2O \qquad \longrightarrow H\cdot + (OH)'$$
$$2H\cdot \qquad \longrightarrow 2H + 2\oplus$$
$$2H + O_2 \longrightarrow H_2O_2$$
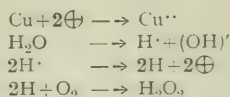
i.e. two hydrogen ions have given up their charges to two copper ions. If it be considered untenable to suppose that any hydrogen could separate out, even momentarily, as is required by the above reactions, then the series given below may be preferred, as better representing the mechanism of the solution of copper. In these the catalytic action of the metal is supposed to bring about the oxidation of H_2O to H_2O_2 in the presence of copper.

$$Cu + 2\oplus \qquad \longrightarrow Cu\cdot\cdot$$
$$O + H_2O + 2\ominus \longrightarrow 2(OH)'$$
$$2(OH)' + 2H\cdot \longrightarrow H_2O_2.$$
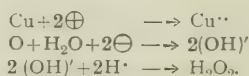
The nett result of which is that two hydrogen ions have given up their charges to the two copper ions, as before.

The primary process of solution of copper in acids or sea-water being accounted for in one or other of these ways, it remains to trace the reactions which take place subsequently. Owing to the peculiar conditions of very slight alkalinity which exist in the sea-water in the neighbourhood of the copper, a basic salt of the composition $Cu_4OH_6Cl_2,H_2O$ (in which two chlorine atoms have replaced two of the (OH) groups of the normal copper hydroxide) is formed. This salt is practically insoluble, and will separate out on the copper, and may become rather firmly attached to it if the conditions be favourable. A deposit of this sort may possibly act as an electro-negative area, thereby promoting the solution of electro-positive copper in its neighbourhood, as has been suggested by Tilden. The result may, possibly, be a pit. It must be reiterated here, however, that the basic salt can only act in this way if it is a conductor of electricity, and the present author has not been able to discover any evidences

* Traube, *Berichte Chemischen Gesellschaft*, xviii. 1877–1888.

either for or against its behaviour in this respect. This point, therefore, should be cleared up at once. If it be proved that this material can function as an electro-negative node, then it will be worth while, when dealing with the corrosion of copper pipes, to take such precautions as are possible to destroy the conditions under which this salt is formed; but pending further evidence on this point, these conditions need not be further discussed.

The next point of interest in connection with copper to which, in the present author's opinion, particular attention should be paid, is the fact that pure electrolytic copper, as it comes on to the market in the form of pipes and tubes, is not infrequently more readily corroded than pipes of ordinary good quality copper which has been merely furnace refined.

In several shipyards known to the author, the engineers and managers have found corrosion to be so frequent in electro-refined copper pipes that they prefer the fire-refined and drawn tubes. The author has seen several examples of badly corroded tubes of electro-deposited copper, and in one or two cases where junctions between electro-copper and furnace refined copper tubes had been made, the latter has been completely free from corrosion and the electro-copper tube has been severely corroded.*

Hamlet † and Muntz ‡ both express the opinion that electrolytic copper is more corrodible than ordinary "best select," and even carries this property with it into brass alloys prepared from it. There can be no doubt, too, that this opinion is shared by many practical men who have to deal with alloys which come in contact with sea-water.

Now at first sight one would expect electro-deposited copper to be almost an ideal material for resisting corrosion. It is one of the purest of all commercial products. Cowper

* This paragraph is perhaps too elliptical. Pipes are made of electro-refined cathodes, which are melted, cast, and subsequently drawn. Oxygen will be present in such tubes, but will not be present in tubes formed directly by electro-deposition, as in the Elmore and Cowper-Coles processes. This may constitute an important difference. It is not possible very often to find out from the users of so-called "electro-copper tubes" by which process they have been made.

† *Loc. cit.*

‡ *Loc. cit.* See also discussion on Rhead's paper, *Journal of the Institute of Metals*, 1909, vol. ii.

Coles * gives the following analysis of copper deposited in
his centrifugal process of pipe manufacture :—

									Per Cent.
Iron	.	.	.	.	.	.	.	.	0·0189
Arsenic	.	.	.	.	.	.	.	.	0·0015
Lead	.	.	.	.	.	.	.	.	0·0013
Antimony	.	.	.	.	.	.	.	.	0·0010
Bismuth	.	.	.	.	.	.	.	.	0·0008
Silver	.	.	.	.	.	.	.	.	absent
Nickel	.	.	.	.	.	.	.	.	,,
Sulphur	.	.	.	.	.	.	.	.	,,
Copper (by difference)		.	.	.	.	.			99·9763

It will be noticed that all the ordinary metallic impurities
have been carefully estimated, and are present only in very
small amounts.   Probably the copper deposited by the
Elmore process is of approximately equal purity.   Under
the microscope copper of this type would appear to con-
sist of polygonal homogeneous crystals.   It is to be expected,
too, that the metal will be very uniform physically.   In the
Elmore process the only " work " put on the metal is done
by an agate burnisher which passes at regular intervals over
the newly deposited copper, and the action of this burnisher
might certainly be expected to be very uniform.   The object
of the burnisher is to give as dense and homogeneous a metal
as possible.   In the Cowper-Coles centrifugal process the
cathode is rotated at a high speed to secure the same end,
and to avoid laminations in the metal.   In both cases the
tubes may be " drawn " after deposition.   That both pro-
cesses are successful in producing uniform material is shown
by the fact that the tensile strength and other physical
properties of the electro tubes are fully equal to those made
by the ordinary process.   For instance, Cowper Coles † states
that tubes made by the centrifugal process have given a
maximum stress of 17 tons per square inch, and after
drawing have withstood a pressure of 3000 lbs. per square
inch.

These facts evidently point to some factor which influ-
ences very seriously the whole problem of corrosion, and
which, curiously enough, seems to have been almost entirely
omitted from consideration by previous writers on the subject.

* *Journal of the Faraday Society*, 1903, vol. i. p. 3.   † *Ibid.*

The extraordinary nature of this omission is well shown by the following considerations :—

    (*a*) There is much evidence to show that Muntz metal is less readily corroded than ordinary best select copper.

    (*b*) Best select copper is frequently less readily corroded than electrolytic copper.

    (*c*) Hence, we may conclude that electro copper is much more readily corroded than Muntz metal.

Now in Muntz metal, so far as our knowledge has taken us up to this point, we have apparently excellent conditions for rapid corrosion, namely two conducting materials (the α and β phases) in intimate contact with each other, one of which has a greater solution tension than the other. In electro-copper, on the other hand, we have an apparently ideal material for resisting corrosion. Yet, in practice, the latter is more easily corroded than the former.

It is evident, then, that there is a factor influencing corrosion that may, in certain cases, become even more important than the mere juxtaposition of two phases, a factor which has been overlooked, partly perhaps owing to the fact that the attention of the investigators has been too exclusively concentrated on another well-ascertained phase of the problem, and partly because too great a dependence has been placed upon the indications of the microscope for the determination of differences in chemical composition.

There appear to be two possible factors influencing corrosion which have not hitherto received sufficient investigation :

    (1) The type of crystalline structure and texture of the metal or alloy. For instance, fine or coarse crystallisation, porosity, laminations, &c.

    (2) The fact that the presence of small quantities of impurity in solid solution may very well have considerable influence on the solution pressure, and the depolarising action of the metal.

Factor (1) above appears to the present author to deserve more attention than it has hitherto received, but probably

if it had been of any great importance it could not have escaped the detailed investigation of microscopists.

Factor (2) appears to be the one to which attention should be particularly paid in the immediate future. A considerable amount of evidence pointing to the importance of this matter may be gathered from this report, and the recognition of the importance of this factor goes some way towards explaining some of the conflicting conclusions arrived at by previous workers.

Impurities existing in solid solution in an alloy may affect the corrosion problem in several ways :

(1) They may alter the solution pressure of the metal.
(2) They may function as depolarisers, *i.e.* they may facilitate the removal of H ions from solution.
(3) If they are irregularly distributed, they may produce negative and positive areas in the metal or alloy.

Alteration in the Solution Pressure of the Metal.

There are very few data showing how the solution pressure of an industrial or nearly pure metal varies with the contained impurity, but it is interesting to consider under this heading the effect of tin on Muntz metal and brass. Muntz metal, if quite pure, should always show rapid corrosion and dezincification for reasons already noticed. In practice it usually shows great resistance to the attack of sea-water, and the presence of tin appears to increase its resisting power. Now when the total amount of tin present does not exceed about 1·5 per cent. the whole of the tin will exist in the Muntz metal in a state of solid solution. The quantitative distribution of the tin between the two phases does not seem to have been accurately ascertained. It appears to be present in both α and β crystals, but in somewhat greater proportion in the β crystals. Now any substance in solid solution in a metal or alloy will affect in some degree its solution pressure. If we consider that the tin lowers the solution pressure of the crystals in proportion to its concentration, it may very well happen that it will lower that of the β phase down to that of the α, so that the two will be very nearly equal. It follows

that there will be very little tendency towards the formation of positive and negative areas in the alloy, and the preferential attack on the β crystals which gives rise to dezincification will be greatly checked, if not entirely stopped ; in other words, the corrosion will affect the two phases indifferently, and the areas at which the attack will occur will be mainly determined by slight and chance variations in the state of the metal at different localities. Such slight variations may be due to strain, slight oxidation, the presence of traces of grease, &c., and the polarity due to them will probably be frequently reversed. Also the amount of corrosion due to such causes will be very small and fairly uniformly distributed, and in such circumstances the life of a Muntz metal plate may be greatly prolonged. The protective influence of tin on $70 : 30$ brass may be accounted for along similar lines if we suppose that the β phase is present in solid solution in the α, and that dezincification is started by an attack on the β; the polarity will of course be reversed when much of the zinc has been removed.

The exact proportion of tin which should produce the effect described cannot be definitely stated, and it is not even certain that it will actually function in the way outlined above. The present author thinks that there are many indications which point to its doing so, and if it does not, other metals may. At any rate the matter appears to deserve careful experimental investigation in the immediate future.

Alternatively the action of the tin may be regarded as a depolarising one, and that it increases the corrodibility of α. As a consequence the total corrosion might be greater but more uniform.

The principle suggested as the action of tin may of course be applied to any other metals which exist in solid solution in industrial alloys. Some of these metals will lower and others will raise the solution pressure and depolarising properties of the phases present in the alloy, and consequently they will affect beneficially or otherwise the behaviour of the alloy towards corrosive solutions.

The cause of the rapid corrosion of electrolytic copper may be usefully considered from the same point of view. Such

copper almost invariably contains a certain quantity of hydrogen gas, absorbed, or in solid solution, or present in a definite compound, and the presence of this gas may perhaps be the cause of a greater tendency to corrosion than that shown by ordinary B.S. copper. On the other hand, the difference may be due to the presence of small quantities of a protecting metal in the less pure material.

It is obvious that a wide, and hitherto unexplored, field for investigation is opened by these suggestions.

The Function of Impurities as Depolarisers.

Any impurity, whether present in solid solution or not, may act as a depolariser, *i.e.* it may assist in the rapid removal of hydrogen ions from solution. For instance, cuprous oxide may react with nascent hydrogen to form water and metallic copper, and thus promote the rapid removal of hydrogen from solution. The present author believes that the oxide functions in this way, Milton and Larke and others consider that it promotes corrosion by forming electro-negative nodes, and F. Johnson * believes that in small quantities it actually hinders corrosion. The depolarising action may also be a purely physical one. Hardly anything definite can be said under this heading till more experimental results are available.

It should also be borne in mind that small quantities of certain substances present in the corroding liquid may function as depolarisers and assist corrosion, or they may act in the opposite sense and retard corrosion.†

The Distribution of Impurities in Solid Solution.

Very little work has been done upon the exact distribution of the small quantities of impurities which are always present in solid solution in non-ferrous metals and alloys. It is usually tacitly assumed that the distribution is uniform. This is by no means certain to be the case unless the alloy has undergone long annealing. It would be interesting to make a series of analyses of samples taken from different points on a large

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* F. Johnson, *Metallurgical and Chemical Engineering*, vol. viii. No. 10.
† Burgess, *Electrochemical and Metallurgical Industry*, vol. iv. p. 384.

casting—such a casting as is used for the manufacture of condenser tubes. If any irregularity were shown to exist, it would have an important bearing on the corrosion problem, for it is not likely that such segregation would be removed entirely by the subsequent annealing for short periods as ordinarily carried out. Probably many manufacturers are in possession of data which would throw much light on this question, and it is much to be hoped that they will bring them before the Institute at its forthcoming meeting.

SECTION VI.

DISCUSSION OF "ACCELERATION TESTS"—OUTLINES OF A RESEARCH SCHEME.

The task of drawing up a series of proposals embodying a research scheme is, at present, one of unusual difficulty. A study of the discussions which have taken place upon the papers on corrosion shows clearly that decided opinions have been formed by some speakers upon certain phases of the corrosion problem. But the details of the experiments upon which these opinions have been formed have not been published in many cases; in consequence the present author has no means of comparing and correlating them with the published work; also the opinions expressed by different speakers are, in some cases, mutually contradictory, and there are no means of distinguishing the true from the false.

In arranging the research scheme presented below, no factor in the problem of corrosion has been considered as proved unless it has been satisfactorily investigated by *published* experimental work. In the present author's opinion few such factors have been so established. In the meantime it is not possible to interpret many of the results met with in practical work. A broader scientific foundation must be laid for the whole subject, and it is hoped that this report, and the results of work proposed in it, may in some small measure assist in laying such a foundation.

It is proposed to carry out, side by side, two series of experiments; the object of one series is to accumulate scientific data for the more minute study of the problem (Series II.); that of the other to secure results that may be of immediate practical interest (Series I.). In this series of experiments only one or two of the simpler problems, out of the great number involved, can be usefully attacked at present, *i.e.* until some results have been obtained from experiments in Series II.

Suggested Experiments.

Series I.—In studying the problem of corrosion several authors have found it convenient to use some form of acceleration test, *i.e.* some test in which the speed of the process of solution of the metal is increased artificially. The principal methods available for this purpose are :—

1. To increase the temperature of the corroding solution.
2. To increase the concentration of hydrogen ions in the solution, *e.g.* to use acids instead of salt solutions.
3. To use an external electromotive force.

The establishment of a recognised standard acceleration test would be a great boon to manufacturers and users of metals alike, but as far as the present author is aware no systematic attempts have hitherto been made to ascertain whether or not such a test can be devised, so far as non-ferrous materials are concerned.

In the case of iron and steel an acid acceleration test has been proposed, and has been adopted to some extent, especially in America. Nevertheless, certain authorities absolutely deny its utility, and Committee U of the American Society for Testing Materials has reported that the acid test should not be used to decide the relative resistance to corrosion of different types of iron and steel. Notwithstanding this expression of opinion, they have laid down careful regulations for the carrying out of the test.

Cushman and Gardner sum this matter up in the following words : " Owing to the nature of corrosion it is probably true

that no perfectly reliable test for corrosion resistance can be devised. Corrosion in the natural process of rust formation—that is to say, in very slightly acid media—is a question of comparatively slow growth under special conditions, and any effort to hasten the action changes all the conditions of equilibrium, producing an entirely different order of phenomena. Nevertheless, evidence has been brought out . . . to show that stresses and strains as the result of cold rolling or imperfect annealing of steel will affect not only the degree of solubility in acid, but also the tendency to maintain differences of surface potential affecting the rapidity of corrosion. In view of this it is probable that when its limitations are understood, and its results properly interpreted, the acid test will be useful in the hands of competent investigators."

The present author's views are in accord with this statement, and he believes it to be well worth while to study experimentally the several types of acceleration test mentioned below. In the first instance, the work should be confined to one kind of material only, say any one standard type of 70 : 30 brass. The scheme of work suggested is as follows :—

A set of forty-eight condenser tubes in 3 feet lengths to be submitted to the action of natural sea-water in the apparatus shown in Fig. 4, which is self-explanatory. This apparatus has been designed to represent average service conditions as far as is possible on a small experimental scale. The present author believes that service conditions are so variable amongst themselves that it is useless to attempt a very close approximation to any one particular set, and he believes that very useful data can be obtained from the plant figured. No attempt has been made to arrange for the study of erosion on the steam side.

Arrangements have been made for varying the speed of the water in the tubes. The speeds used might be in the ratio of 1 : 2 : 4 : 8. The effect of stagnant water should also be studied by sealing the ends of one or two tubes.

The important question of the way in which the choking of a tube affects corrosion might also be usefully studied. For instance, when such materials as ashes, shells, seaweed,
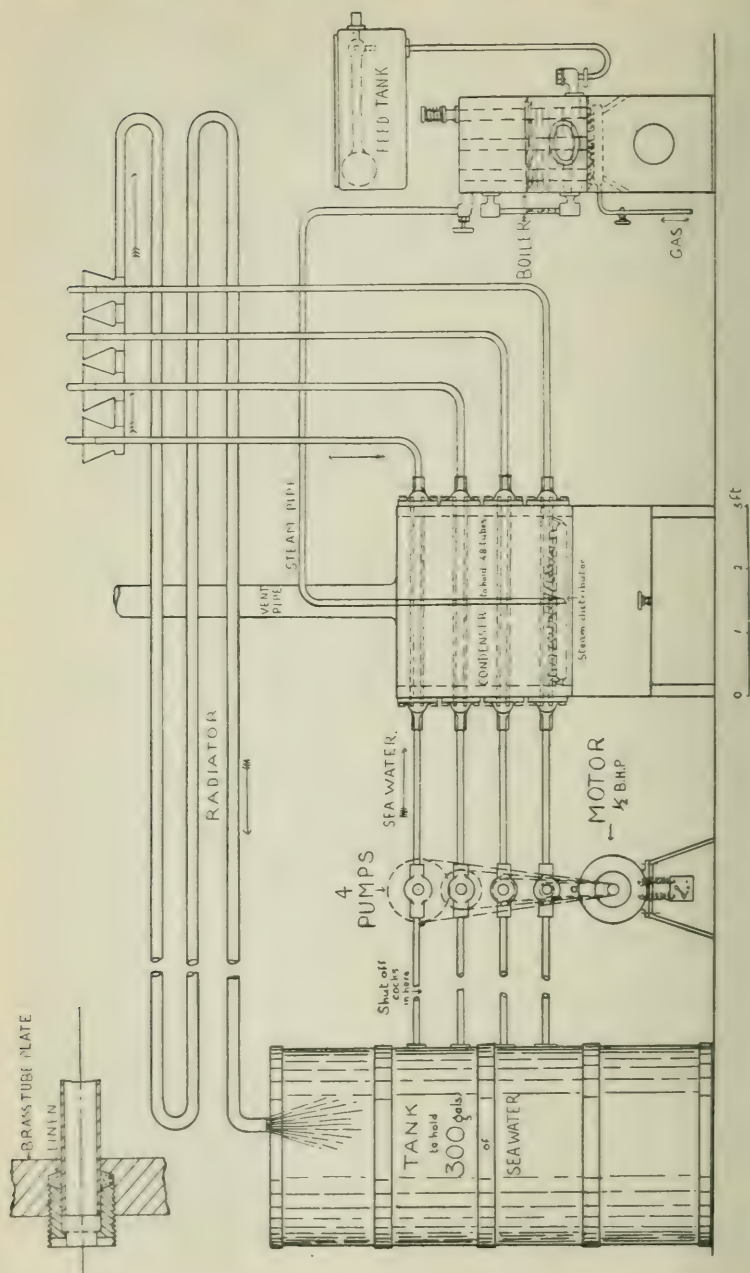
FIG. 4.

&c., choke the tubes they may affect it in any of the following ways :—

1. By merely stopping the flow of water ; stagnant water has been suggested as a cause of corrosion.
2. By allowing the tube to become over-heated, and so accelerating the speed of the corrosive action.
3. By acting as electro-negative areas.

If it could be definitely ascertained in which of these three ways (if in any of them) such materials spoilt the tubes, a definite advance in our knowledge of the subject would have been made, even if no remedy at once suggested itself.

Several other subjects might usefully be studied in this apparatus, *e.g.* the effect (if any) of the presence in the tubes of deposits of ferric oxide and basic chloride, since considerable differences of opinion exists as to the effect of both these substances.

In all cases the tubes would be weighed before and after the experiments, and the interior surfaces of the tubes examined microscopically at the end of the test. Certain tubes would be replaced by glass tubes containing short lengths of half sections of the tubes ; these would be examined at intervals and are to be regarded as "guide tubes," used for the purpose of following the course of the corrosion in the other tubes. This test would be carried on uninterruptedly for a year at least, and some of the tubes would have to be corroded for a very much longer time.

Simultaneously with the main test portions cut off the same tubes would be tested under three sets of conditions, in each of which the rate of corrosion could be accelerated in one of the following ways :—

1. By increasing the temperature of the corroding liquid (sea-water).
2. By using acids instead of sea-water :
   (*a*) With air bubbled through the acid.
   (*b*) Without air bubbled through the acid.
3. By using a small external electromotive force

The results obtained by these tests to be compared with those of the main test.

Series II.—A series of electrode potential or " over-voltage " experiments would be made on copper and brass, both pure and with definite quantities of added impurities, the particular object being to ascertain their effect on solution pressure, and also their depolarising action.

In submitting this scheme of experimental work the present author wishes to point out that it is directed towards elucidating only one or two of the factors in the very complicated problem of corrosion.   The author believes that there is no other line of research which requires a slower and more cautious advance than this one.   No step should be taken until the ground covered has been thoroughly explored by repeated observation and experiment.   If some members believe that they are already in possession of information which enables them to answer some of the problems proposed to be investigated, the present author would point out that experiments with the same object in view, but carried out in a different way, frequently bring new and unexpected light to bear on a subject, and even if this should not happen, the cumulative weight of separate sets of experiments which confirm each other is an important asset, especially in such a subject as corrosion.

DISCUSSION.

Mr. Bengough said that, with the permission of the President, he desired to mention one or two points referred to in the Report, and slightly to modify some of the statements therein made. Half-way down page 51 the statement occurred: "Hence it is reasonable to assume that an increase of electromotive force will have the effect of pushing the less electro-positive copper into solution to assist in carrying the current. Hence, with an external electromotive force, the relative corrosion will not be the same as without that electromotive force." He wished to emphasise that point. If the corrosion of condenser tubes be due to current leakage, and the E.M.F. between the corroding point and its cathode be considerable, then the corrosion would be great in total amount, but the removal of the zinc would be in less proportion than usual as compared with the copper. On page 86 a diagram was given of a proposed experimental plant. That diagram was out of place, owing to a confusion between himself and the printers. It was labelled Fig. 4, and it was referred to in the text nearly at the end of the paper as Plate I. For instance, half-way down page 85 he referred to " A set of forty-eight condenser tubes in 3 feet lengths to be submitted to the action of natural sea-water in the apparatus figured in Plate I." Plate I. should of course really read Fig. 4. There was a point on page 56 in regard to which he desired to obtain the opinion of the members. He there gave a summary of Mr. Isherwood's views on corrosion, the second of his conclusions being given in paragraph 3 on that page : " The larger the mass of metal exposed to corrosion, other things equal, the smaller will be the rate of its corrosion." That seemed a very extraordinary opinion to hold, and, as far as he could see, there was no explanation for it. He had several times met practical men who held that opinion, so that although at first sight it looked a very extraordinary one, almost absurd, it was quite largely held by engineers. The point was therefore worth considering, and he asked the members to say whether they also had found that if they used a thicker condenser tube than usual, less corrosion, not only relatively but absolutely, was obtained. The influence of mass seemed to have some extraordinary effect on the rate of corrosion. Personally he could not understand the point, and he should like some light thrown on it. At the top of page 60 it would be noticed the statement was made that Charpy, the eminent French metallurgist, gave a series of reactions set out in the Report as representing the action of sea-water on copper. He had inserted into the paper the reactions exactly as given by Charpy. In the fourth equation it would be noticed that the two sides did not balance ; a 3 had been dropped apparently on the right-hand side of the equation, but the equation was printed exactly as given by Charpy, and as he was quoting from the French metallurgist he had not dared to make any alterations himself ; he simply desired to draw attention to the point. The paragraph beginning " In several shipyards known to the author " on page 77 might appear, in his attempt to cut down the length

of the paper, rather elliptical. He had not, in the paragraph as written, sufficiently distinguished between electro-deposited pipes or tubes and tubes that were made out of electro-copper, which was then melted, cast into ingots, and then drawn into tubes. In the paragraph to which he referred the words "electro-refined copper pipes" meant that the pipes were made from copper cathodes that had been cast and then drawn. Two lines below that "an electro-deposited copper tube" meant a tube that had been deposited on a revolving mandril. Whether or not there was any difference in the behaviour towards the corroding agents of those two forms of electro-copper he was quite unable to say at present, and there did not seem to be any reference to it in the literature of the subject. The point was a very interesting one, and at some future time perhaps would be deserving of detailed investigation. He desired to make a short addendum to page 83. In a recent number of the *Journal of the Society of Chemical Industry* two Australian authors, Messrs. Harker and McNamara, had made a large number of experiments with Cumberland's method of protecting boilers from corrosion, and they had obtained some rather interesting results. Those results applied in their case only to iron and steel, but he thought the principle which had been discovered could and should be extended to apply also to the corrosion of copper alloys. Cumberland's process for protecting steel boilers from corrosion was to suspend in the boiler space a bar of wrought iron, and to pass a small current from that bar of wrought iron to the shell of the boiler as a cathode. Those two authors investigated the conditions that obtained when that process was carried out, and tried to ascertain whether the current alone was responsible for the protection, or whether it was really the ions in solution that protected the shell from corrosion. They discovered that if a platinum anode and a steel cathode were used it was necessary to employ a very much larger current to prevent the cathode from corroding than if an iron anode was employed. It had to be so large that it could not be applied economically on a practical scale. If, however, a steel anode was substituted for the platinum anode a very small current was required, and they could be used economically on a large scale. Those investigators came to the conclusion, therefore, that the protection from corrosion of the cathode was due to a continual solution and deposition of iron. Applying that principle to condenser tubes, it would be found that if an endeavour were made to protect condenser tubes by putting strips of iron into a condenser there would still be a certain small amount of corrosion going on; but if an attempt were made to protect it by means of a brass of some kind that gave off zinc ions, and a current passed of such strength that the zinc ions began to go into solution, then complete protection ought to be obtained. That was an experiment that was very well worth trying. Supposing they took a cast brass of 50 per cent. copper and 50 per cent. zinc and passed a very small current through it, that, according to Harker and McNamara, should entirely protect the condenser tubes from corrosion, and it would be a far more efficient protector than any form of iron, or steel, or anything except zinc. It would, of course, have a less protective influence than zinc, but zinc was corroded away more rapidly, and would require

such continual renewal that it might not be applicable commercially. In view of the work which had been done on the subject, he thought that experiment might be tried to see whether a 50 : 50 brass would completely protect condenser tubes from all corrosion. With regard to the last page of the Report, in view of the paper which was to be read at the meeting by Professor Carpenter and Mr. Edwards, he thought it was necessary to add to the list of desirable factors to be experimented with, the influence of annealing temperatures on the corrosion of condenser tubes. He was not prepared at present to submit an exact plan of how that should be carried out ; he would like first of all to talk the matter over with gentlemen who were connected with the manufacture of tubes, but he thought it was a subject which must be clearly borne in mind when dealing with the investigation of the problem. He also wished at the end of his paper to extend his thanks, which he had not done in the preliminary copy, for a bibliography that was sent to him by the Carnegie Library at Pittsburg. That library had compiled a most valuable bibliography on the corrosion of metals generally, not only of non-ferrous metals, but also of iron and steel. It brought the whole subject up to the end of 1908, and it had been a very great help to him in compiling the Report.

Sir William A. Tilden, F.R.S. (London), said he felt that he was scarcely a competent critic of so important and voluminous a paper, especially because it was so many years since he did any work on the subject. Some twenty-five years ago he published a paper in the *Journal of the Society of Chemical Industry*, and he regretted to say that, as it was only on the previous evening that he heard the present paper was to be read, he had not had an opportunity of refreshing his memory as to what he then said. That paper contained several absurd misprints, which, however, would not materially affect the sense. If he were writing that paper at the present time he would no doubt change the phraseology a little to bring it into harmony with more modern theories. But while he perhaps might alter the phraseology of his paper, he did not feel disposed to withdraw any of the facts that were set forth in it. They were very carefully observed, and a great many experiments were done which were not actually recorded, all of which pointed in the same direction. On looking through the Report, which he had only been able to examine imperfectly, he was glad to find that the great majority of authors appeared to agree that the action was electrolytic. Personally he felt certain that that was the case. But what the substance or substances were which were most effective in causing that kind of change to take place was, he presumed, one of the principal subjects of the inquiry which was to be undertaken. There was one thing he noticed in which his conclusions were opposed to those of one of the other authors quoted in the paper. He noticed that Utheman had proposed to protect condenser tubes by putting coils of iron inside them. As long as the iron was there in the metallic form no doubt protection was afforded, but he came to the conclusion that the oxide that resulted from the rusting of iron if deposited locally was one of the causes of corrosion in the brass tubes that he examined twenty-five years ago ; and although the author in the Report

had treated all the scientific investigators very fairly, he did not notice that he had quoted his (Sir William's) conclusion in reference to that matter. One of the causes of corrosion along the lower surface of the condenser tube might, he had supposed, possibly be chips of iron and iron filings carelessly left inside. He made an experiment, which consisted in circulating for several weeks hot sea-water through a tube with a piece of iron inside, and he certainly succeeded in establishing corrosion in a brass tube in contact with a piece of rusted iron. There appeared to be some doubt in the mind of the author of the Report as to the possible electrical properties of the oxides in the substances that were formed by the corrosion of the metal. He did not know of the existence of any direct determinations either as to the conducting power or other electrical properties of the oxide or oxychlorides of copper. In the case of iron that had undoubtedly been established. Ferric oxide in contact with iron formed a couple in which the oxide was negative. But whether that was the case or not, the presence of a substance like an oxide formed by the process of corrosion would act as a depolariser, when the tube was empty or when the substance was exposed to the air, by absorbing air, as all porous substances did, and in that way tending to localise the effect. Two or three years ago he occupied himself with the somewhat similar question of the rusting of iron, and came to the conclusion that the action was unquestionably electrolytic. In the case of iron, the accelerating effect was produced by the presence of carbonic acid in ordinary air : but that iron could be oxidised by pure water alone he was quite certain, notwithstanding the rather confident statements that had been made by other people. Those differences of opinion only served to indicate how extremely difficult was an investigation of the kind undertaken by the Corrosion Committee. The only suggestion he wished to make with regard to the experiments that were proposed was, that as far as possible the conditions obtaining in practice should be imitated as closely as they could be. There was no doubt a good deal of difference between cold and hot sea-water, because the salts in the solution were undoubtedly more or less hydrolysed, and their effects upon any metallic surface would be very different at the temperature which prevailed inside the condenser tube from what it would be at the atmospheric temperature. He thought that in the case of condenser tubes a good deal of the mischief was done while the vessels were in port and the tubes were empty, *i.e.* when they were lying with a little water extending along the bottom so that the air had free access at the same time. That question was, he understood, to be further investigated, and he wished the Committee every success in their interesting inquiry.

Dr. W. Rosenhain, Member of Council, said that when he had expressed his intention of taking part in this discussion he had not seen the Report, and he now found that there were only one or two points which he desired to mention. In the first place, he thought the Report was of very great value in clearing the ground for a research of the kind which was to be undertaken. It had put before the members in a concise way —and he said it was concise in spite of its volume—the result of a very

large number of investigations. There were one or two questions, however, which perhaps it might be worth while to consider. The author had raised the question of the scale of the microstructure, *i.e.* the size of the crystals, affecting corrosion ; the statement had been made that if such an influence had actually existed it would have been noticed before by microscopists. He thought he was justified in saying that he had noticed something of that kind, and the general evidence, so far as it went, was that the larger the structure the more liable the brass was to pitting, *i.e.* not to dezincification, but to intense local corrosion. Whether the scale of the microstructure had any connection or not with the question of dezincification he was unable to say, but there seemed to be quite a definite amount of evidence to show that in brass tubes, 70 : 30 principally, the coarser the structure the more liable they were to pitting. That evidence was based on the examination of perhaps forty or fifty different corroded tubes, and though it was not based on a large amount of evidence, so far as it went it was worth bearing in mind. That suggested another line of thought, namely, that the size of the crystals would depend undoubtedly upon two things—the mechanical and the thermal treatment which the metal had received. It had recently been shown by the researches of Cohen and Charpy that the rate at which the crystals of a metal grew when that metal was annealed depended upon the amount of the cold mechanical deformation which they had received beforehand. In other words, if a piece of brass was taken which had been only just lightly strained, and another piece was taken which had been severely strained, and the two were heated together, a coarser structure would be obtained in that brass which was originally more severely strained. Charpy had shown conclusively that the same principle applied to steel. It seemed to him there was a possibility of that kind of thing arising, possibly from unequal mechanical treatment in different parts of the same tube in the drawing process. In the drawing process there was a very severe mechanical deformation going on, and the question was, Could that process be so regulated that the mechanical deformation was uniform throughout the circumference of the tube ? He was not referring so much to skin effects on the outside and inside of the tube, although they might play a part, but rather to the fact that the substance of the tube was not of uniform thickness all through. Consequently one side of the tube had perhaps been drawn a little more severely than the other, and that might lead to differences of structure, which would lead to possible differences in corrodibility in different parts. His own feeling about pitting, from the tubes he had seen, was that it must be associated with something in the metal itself, for the reason that the pitting nearly always occurred on very well defined lines along the length of the tube. If it was in the bottom of the tube it would be simple enough to explain it on the basis of water being left in when the tubes were empty, but it was not always at the bottom. He had traced lines on one side, and in other cases he had noticed several lines of pits ; in fact they were sometimes not only pits but actual grooves which had been corroded. How could that be accounted for except by the presence of something in the metal ?—it might be an impurity, or it might be a mechanical difference

of the kind he had indicated. He did not desire to go more fully into the question at the present time, because it was necessary that it should be thoroughly investigated, and the members all hoped that this work would be carried out by the Committee. He thought the best thing to do was to wait for the results of that investigation before making any further remarks on the subject. There was one little suggestion, however, which he desired to make, namely, a test of a very simple kind which he had often found useful in giving fairly reasonable indications of the properties of brass and copper from that point of view. If a specimen of the metal was polished, and a single drop of strong nitric acid was dropped on it and then washed off immediately, probably by the time it was washed off the nitric acid had exhausted itself. If that procedure was carried out, it would be found that the surface of the alloy or of the copper had been etched, and not only had it developed to a greater or less extent the outlines of the crystalline structure, but it had developed a large number of pits, which, under the microscope, appeared as black spots. Those black spots varied very much in size and in number in different kinds of brass and copper. So far as the actual comparison of those tests went, there was no doubt whatever of the tendency of the metal subsequently to corrode in use. If the specimens were taken in which the corrosion was obvious, it would be found that they showed a very large number of those black spots after etching in the manner he had described. It was a sort of rough kind of acceleration test, but so far as it went it was very instructive. Those black spots were due to the presence of particles of impurity ; they were certainly caused by the presence of particles of lead in a brass ; and he thought—although he was not absolutely certain—that oxide of copper, in the case of copper tubes, would do exactly the same thing. What it would do in brass he was not quite so certain ; that was a more difficult matter. Then, again, the Cushman jelly test was applicable also to brass and copper. If the jelly containing the phenolpthalein and ferrocyanide were placed on a sheet of brass, signs were obtained of the same kind of local action which occurs in steel, and he believed that this principle might be of use. There was no doubt whatever that the Report was a most valuable first step in the work of the Corrosion Committee, and the members might take it as a promise of what was yet to come.

Mr. A. E. Seaton, Member of Council, said he had not intended to obtrude himself on the meeting, there being so many present more competent to speak than he on such a highly scientific Report ; but some observations of Dr. Rosenhain turned his mind into a channel he had followed some months ago ; he thought he might be able therefore to make a few remarks which might throw a little light on what had been said. The members might be aware that about forty years ago brass boiler tubes were very largely used in the Navy ; in fact up to that time naval boilers had almost universally brass tubes ; the stay tubes, of course, were made of iron. Those brass tubes were much thicker than the condenser tube, being generally 10 or 11 gauge thick. The composition was 68 and 32, so that it was slightly different from that of the condenser tube ; he did

not remember any cases of pitting or any similar trouble with those tubes. Perhaps his friend, Admiral Corner, who was to read a paper later on, who had had some experience in that respect, might be able to say something on the subject; but personally he did not remember any complaints of corrosion of such boiler tubes. Of course eventually they wore out, but that was due rather to the mechanical action of the hot gases and grit passing through the inside. But perhaps the chief point to which he should call attention was that similar troubles to those of condenser tubes were now experienced with thin steel boiler tubes. That reminded him that, whereas formerly condenser tubes were usually 16 to 18 gauge thick, they were now seldom so thick; in fact, for the sake of lightness, the users had gone in for the lighter gauges; whether that had anything to do with the corrosion question or not he was not prepared to say. It was no secret that it was a practical impossibility so far for makers to draw thin steel tubes of British steel sufficiently good to pass the Admiralty inspections and tests; to do so successfully it was necessary to use Swedish steel. All attempts to draw small tubes of high quality from a purely British steel had failed. Now steel tubes were drawn pretty much in the same way as condenser tubes, *i.e.* there was a hot process and a cold process, and the cold drawing was pretty severe on the steel. The fact remained, however, that whereas with the Swedish steel it was possible to draw a tube of comparatively small thickness, with an internal and external surface that would pass the most rigid inspection, even after immersion in a bath of a weak solution of acid, with the British steel very much the same defects are shown and the same indications are noticeable as with the condenser tubes made of the metal recently referred to by Professor Rosenhain. It was hardly necessary for him to say that the British steel was not so pure as the Swedish, and so far it had been found impossible to produce from a British ore a steel which would permit of its being drawn out into a small, thin tube sufficiently good for the Admiralty. It was possible to produce a steel in this country that would do so, but such steel was made from foreign ore. It had occurred to him that in the old days, when tallow was used in the cylinders and a non-mineral oil as a lubricant, no complaints were received that pitting existed as it did to-day. Excessive pitting seems to be coincident with the use of mineral oils, although there may be no connection with it. He distinctly remembered the condenser of H.M.S. *Bellerophon* being almost completely choked with what was called copper soap—a green stuff similar to soap, which required a deal of digging out. He had also seen a condenser quite half full of a greasy deposit; in both cases the tubes were sound and in as good a condition as when put in. In the latter case, however, he was bound to say the tube plates were of cast iron, and in both cases wooden ferrules were used. He had never known a case where the tube plates were of cast iron that the tubes had pitted. The practice of fitting the tubes into tube plates with wooden ferrules, and so insulating them, may have had some effect on their preservation. It is true the iron tube plates used to become soft and in nature like a piece of plumbago. The most severe case of pitting, however, that he could call to his recollection

occurred in a mill at Grimsby, where the circulating water was sea-water obtained from a dead portion of the dock ; the water was therefore stagnant sea-water. When the owner of the mill spoke to him about it, he (Mr. Seaton) told him he thought he could supply him with a set of tubes that would be satisfactory. He thereupon deliberately took some old condenser tubes that had been used in a ship for about ten or fifteen years and were still perfectly good. He thought that if the tubes had stood that service so long they would keep good at the mill. To be quite sure, however, he had the tubes retinned ; but, much to his chagrin, they did not last much longer than those used previously, so that he gave up that mill in despair. He had no doubt now that it was the stagnant sea-water that caused the severe action on the tubes. He had been rather staggered by the suggestion that the thicker the tube the less the absolute corrosion. He had no evidence to give on the subject, but he thought it would be an interesting thing for Mr. Bengough to investigate. We are often told of such paradoxes, as Charles II. misled the Royal Society by the story of the goldfish and the globe of water ; but he liked to see such things demonstrated before he accepted them. To practical men the paper was an admirable one, inasmuch as it gave in a crystallised form information that had been to them more or less nebulous. Moreover, as a practical man, he was able to speak of the excellence of the Institute in having such things put before them by the professorial side so clearly as they did, besides which there are made by them such important investigations. He therefore re-echoed and approved of all the President had said on that subject.

Professor THOMAS TURNER, M.Sc., Honorary Treasurer, said that as he happened to be a member of the Corrosion Committee, he did not propose to make many remarks, as he might have something to do later on with the decisions come to by the Committee. He wished to say, however, that the members were very much indebted to the author for the trouble he had taken in preparing the preliminary Report for the Committee, and for the admirable way in which the Report had been prepared. From the Committee's point of view, however, what was required was criticism of the suggestions made in the direction in which research should go, because the Committee would shortly meet again, and would have to decide upon the line of conduct which should be pursued. The Report contained certain suggestions, and in effect the Committee asked the members whether they approved of those suggestions or whether they could make better ones. The Committee did not wish to embark upon a long, tedious, and costly investigation, and then to be told afterwards by the members that if they had asked their advice at the first stage of the process they would have told them to do something that was very much better. The only contribution he wished to make to the discussion was in regard to the question that had been raised as to the conductivity of the green deposit that was formed on the condensing tubes and on brass generally in sea-water and in air. Some experiments had recently been conducted in his laboratory by Mr. Brühl, which were still in progress, but the preliminary experiments showed that the dry green deposit

was distinctly a non-conductor, and that copper conducted many thousand times more readily than the green deposit. That would appear to show that the green deposit itself could not form part of an electric cell. For an electric cell it was necessary to have two conductors and the conducting liquid. That did not, however, interfere with the suggestion that was originally made by Dr. Tilden, that the green deposit might play an important part in corrosion, *i.e.* that though the substance *per se* was not a conductor, and would not take part in forming a cell, it might absorb a liquid or gas, or act as a depolariser, and in other ways might assist local corrosion when wet or impure, but by itself it could have no objectionable action. Incidentally the proof of that was found in the fact that it was possible to have on brasses and bronzes this green deposit which would last for many hundreds or thousands of years, and which had not led to important corrosion. He had specimens in his own collection on which there was a green deposit over 2000 years old. What he had stated might be a small point to be borne in mind in connection with the discussion, but the primary object of his remarks was for the purpose of stating that he hoped criticism would be forthcoming as to the proposed lines of research.

Dr. J. T. Dunn (Newcastle-on-Tyne) expressed his admiration of the clearness with which the author had presented, not only his summary of the work which had been done on the subject, but also the outlines of the electrolytic theory of corrosion. Whether it was altogether a suitable place for the presentation of those outlines he did not quite know. He had experienced a little difficulty in understanding some of the equations given on page 76, particularly the second set, which he was quite unable to follow, and he hoped the author in his reply would further elucidate them. With regard to his own experience in the matter of corrosion, he was strongly inclined to the belief expressed already by Dr. Rosenhain, that where pitting occurred it was due to local impurities either in or upon the metal, and he was inclined to think that impurities upon the metal, introduced with the water into the condenser tubes, and sticking there for one reason or another, were not infrequently responsible for pitting and similar corrosion. He had found by direct experiment, in consonance with what Dr. Tilden had said, that small pieces of rusty iron did aid in the local corrosion of brass when it was immersed in sea-water. In regard to Professor Turner's remarks, the only suggestion he would like to make to the Committee was perhaps rather a counsel of perfection, considering the expensive nature of the experiments which it was suggested should be carried out. Mr. Bengough said, however, in the very last sentence of the paper that " Even if this should not happen, the cumulative weight of separate sets of experiments which confirm each other is an important asset, especially in such a subject as corrosion." It was continually found in ordinary experiments that if duplicate sets of experiments were made there was some little condition in which the two experiments differed, and in consequence the results of the experiments differed. It was by no means infrequently the case that exactly the same results from a pair of experiments, conducted as far as they

knew under absolutely similar conditions, were not obtained. Further duplicate experiments were then made for the purpose of endeavouring to ascertain what the slight difference of conditions had been. Under ordinary circumstances, where an experiment was made which lasted an hour, or a day, or two or three days, it was not a very serious matter that a definite conclusion could not be arrived at from the first pair of experiments, because they could be so readily repeated ; but if experiments were being undertaken like those suggested by the author, which were to last a year or more than a year, it was a serious matter if an inconclusive result was arrived at, and if, in consequence of that, it was necessary to spend another year in repeating the experiment before one could be quite sure what was the matter. It therefore seemed to him very desirable, if the money could be procured, that in undertaking a set of experiments of that nature, which probably would have such important results, they should not spoil the ship for a ha'porth of tar, or even a hundred pounds' worth of tar, and that the experiments should be set up in duplicate or triplicate in different places under the control of different people, in order, as far as possible, to provide against any indefinite result which they might not be able to interpret from one experiment, but which possibly they might be able to interpret from the results of two or three. That seemed to him a very important suggestion if it could be carried into effect.

Mr. ARNOLD PHILIP (Portsmouth) said he would not encumber his remarks by mentioning the many important points in the paper with which he agreed ; he wished to concentrate his remarks on those parts with which, if he did not altogether disagree, at least he thought a different procedure would be advisable. He would leave destructive and confine himself as far as possible to constructive criticism. His chief objection to the Report was, as a matter of principle, to the method of the experiment which it was proposed to adopt. The author looked at the question rather more from an academic standpoint than he (Mr. Philip) could. He was largely concerned, in his official duties, in the study of the corrosion of metals ; and as he had to deal with a very large number of cases, he was forced to look at the question from a practical standpoint for the purpose of getting some sort of workable result as rapidly as possible. The fundamental oversight in the paper was, in his opinion, that sufficient information had not first been collected from the two important classes of the Institute, namely, the users and the manufacturers. There was a vast amount of information available from the users and the manufacturers which the author had not had before him. In the first place he desired to recite the causes which had so far been suggested as giving rise to corrosion in condenser tubes.

First of all there was the chemical nature of the tubes. In that connection he referred only to the major constituents, *i.e.* the presence in the tubes of 29 per cent. zinc, 70 per cent. copper, and 1·0 per cent. of tin. That composition had in his experience been correct in every case of corrosion that he had examined, and in spite of this, corrosion had occurred. It was astonishing, when one bore in mind what large

quantities of material were turned out by the manufacturers, how uniformly correctly the composition was maintained. He noticed the author stated that his experience with 10 feet long tubes was that they were of remarkably uniform composition from end to end, and that he could not tell the difference between one end and the other as far as the composition was concerned, except by the variations so small as to be ascribable to experimental error. This agreed with his own experience, and he believed that the corrosion of condenser tubes was not often due to faulty chemical composition.

The second suggested cause of corrosion was the contact of dissimilar materials, such as carbon particles and oxide of iron deposited from the cooling water on the lower inside surfaces of the tubes. That in his experience was very often the cause of corrosion in tubes. In some instances which had come before him in which a condenser had broken down seriously, the tubes had been removed and a statistical examination of them had been made. The tubes were marked before they were removed from the condenser, to show which was the bottom and which the top ; and in 90 per cent. of the corroded tubes it was found that the corrosion was along a line on the inside bottom surface. In some cases he had, like Dr. Rosenhain, observed that the corrosion was a line along the side of the tube, and this corrosion was probably due to materials, such as carbon particles, being drawn into the metal on the inside surface of the tubes during manufacture ; but, as he had stated, 90 per cent. of the corrosion appeared in a line along the bottom of the tubes. To his mind that was convincing that such corrosion was to be assigned to the contact of dissimilar substances, such as carbon and iron oxide deposited from the cooling water inside the tubes setting up a voltaic couple.

A third cause of corrosion (or, as the author preferred to describe it, erosion) of such tubes on the steam side had been noticed, but the author had not proposed to deal with that question in the Report. He had, however, himself seen a large number of cases in which such erosion, or corrosion, had occurred. These cases had been carefully investigated, and he thought he had proved absolutely beyond cavil that it was due to the presence of hydrochloric acid, and perhaps to a small extent carbonic acid in the steam which was being condensed. It usually occurred in distiller condenser plants used for making fresh water from sea-water. When portions of the primary steam evaporator coils were exposed above the brine in the steam space, splashes of magnesium chloride formed a white coat upon them ; this became heated and dissociated. The brine in the evaporators always gave a strong red coloration with phenolphthalein, and the condensed steam gave the silver-chloride reaction due to the presence of free hydrochloric acid.

A fourth cause of corrosion was the externally applied electromotive force, *i.e.* leakage from a ship's dynamos or batteries. He had seen cases which he thought must be ascribed to such leakage. Where such leakage existed across a condenser very much depended upon the direction in which it went. For instance, if the positive and negative of the leaky points were at the end of the condenser tubes, the current would largely flow along the tubes, and but little action would take place

compared with what would be the case if the leakage was at right angles to the axes of the condenser tubes. In the latter case, as the current would distribute itself directly as the conductivity of the material and its cross sectional area, and inversely as the lengths of the paths, and would pass from the metal into the salt water and back again, it would certainly corrode the tubes.

A fifth cause of corrosion was said to be due to the mechanical abrasion by currents of steam or water, where the currents carried particles of solid or liquid matter, and even the dry steam itself was said to be capable of this action : he believed that he had seen several cases in which corrosion, or erosion, must be ascribed to this cause.

A sixth cause was the existence of gas, especially air and carbonic acid, in the cooling water. Trouble was experienced in the circulating tubes at bends or joints where these gases were trapped and tended to set up corrosion.

A seventh cause was thermo-chemical action. This had not been referred to in the Report. In considering this action the condenser might be regarded as a thermopile. The condenser tubes (which were not necessarily of the same composition as the shell) joined together two end pieces of different material. If the water flowed in at one end of the tubes where the junction was cool and flowed out at the other end where the junction was hotter, there was a difference of temperature, and in general a thermo-electromotive force was set up which tended to drive a current out from the metal through the sea-water, and back again into the metal ; it did not keep itself entirely to the metal circuits. The electromotive force was no doubt small in amount, but it was necessary to remember that the electrolytic cross-sections were quite large. The experiments which were being carried out by the Committee ought certainly to deal with this question. Other causes to which corrosion had been attributed were : (8) the mechanical strains set up by rolling and heat treatment ; (9) the presence of two or more phases in the alloy ; (10) the intrusion of foreign matter at the surface of the tube in the process of drawing ; (11) and (12) the character and speed of the cooling water ; (13) the presence of minute traces of impurities in the alloy ; (14) the variation in the mass of the corroded metal. Altogether, then, he was aware of these fourteen different causes for corrosion that had been pointed out, and others might exist. His contention was that the experiments carried out by the Committee should be conducted so that thirteen of those fourteen causes might as far as possible be eliminated and kept constant, and the fourteenth as far as possible accentuated and varied, the corresponding variation in corrosion, if any, being measured ; a separate research should, in fact, be concentrated on one particular cause of corrosion. Forty-eight tubes was not a large number to sacrifice to experiments on one single cause of corrosion. Time did not allow of the completion of his criticisms in the discussion, and he desired to be allowed to add some further remarks on Mr. Bengough's Report in writing.

Mr. E. L. Rhead, M.Sc.Tech. (Manchester), desired to join with the previous speakers in expressing his admiration of the valuable Report that

had been presented by Mr. Bengough. As Professor Turner had thrown out the hint that it would be best to deal, at any rate first of all, with the consideration of the experiments which were to be made, and if possible to suggest additions, he should like to point out that, in continuation of a paper that he read some twelve months ago before the Institute, he was carrying out experiments, some of which were included. But in addition it had been his intention to include among the points dealt with the effect of difference of temperature on the inner and the outer walls of the material—the condenser tube. It was his intention to have used some considerable thickness of metal, to have had the same water circulating on both sides; to have kept one at a constant temperature, and to have heated the other; and to determine the effect of temperature difference in increasing the rapidity of corrosion. That the field was quite a new one he was perfectly aware, and there was a possibility of some difference being noted. He noticed that the author had added to the printed list of subjects dealt with the question of annealing temperatures. There was not the slightest doubt that that influenced very greatly the life of the tube, and in that connection it might be well to refer to the remarks made by Dr. Rosenhain in connection with the size of the crystals of the tube. Dr. Rosenhain suggested that the difference in size led to a difference in the rate of attack. Certain manufacturers of brass used for purposes in which they subjected the brass to very heavy mechanical strains in the process of manufacture, had standard photographs of crystals in different sizes, in order to work as far as possible within the limits of the grain, so that a very general uniform effect could be obtained. Another point was in connection with the mass of metal mentioned in the summary of Isherwood's paper given in the Report. Referring to the effect of the mass of the metal and the mass of the tube, he thought when reading it over that possibly the thinner tubes transmitted the heat with greater rapidity and caused more rapid liberation of gas from the condenser water; and the effect of the escaping gas in contact with the tube might account for the more rapid corrosion that took place in such thin tubes. With thick tubes the actual rapidity of increase of temperature of water at the point of entry would be slower; the gas would be given out over a greater length of the tube, and possibly lead to a more uniform effect than when concentrated on a shorter length of tube. He wished also to refer to the question of the corrosion of steel which had been raised by one of the speakers. He had had under examination within the last fortnight some steel tubes that showed more or less similar corrosion to those of brass by being pitted in lines running in the direction of the length. In that case it was found that the trouble arose from the presence of small cavities in the tubes that extended the whole length of the tube more or less regularly, in more or less definite lines, and the conclusion was arrived at that the steel from which such tubes had been made was originally porous; that in the drawing process the vesicles of gas had merely been extended and brought into more or less lineable form, and that that was the direct cause of the failure of the tube. He wished to ask the question whether it was possible that the presence of gases either

in small cavities, or possibly introduced in other ways, might not be responsible for the beginning of the corrosion that was so troublesome in connection with condenser tubes. One other point arose in connection with the remarks made by Dr. Tilden dealing with oxides. He had had some experiments in progress for some little time on the catalytic action of ferric oxide, and had found that under circumstances where it was not possible for electrical effects to enter, where the material had been absolutely dry, but aided by heat, that ferric oxide acted very rapidly as a catalytic agent, and very rapidly increased the transference of oxygen to cuprous substances capable of taking it up. It was more than probable that, under electrical influence and in presence of moisture, that action would take place quite freely, and was directly responsible for the corrosion that was noted in such cases.

Mr. J. H. Heap (London) said that he was almost ashamed to ask the question that was uppermost in his mind, because it might indicate gross neglect in reading the Proceedings of the Institute ; but as there might be a few other members as forgetful as himself, he thought it would be useful information if the President would state at the conclusion of the discussion, for the benefit of those members, how the Corrosion Committee came to be formed, the names of its members, and what steps they had taken so far.

Mr. T. Vaughan Hughes, Assoc.R.S.M. (Birmingham), said that most of the remarks he had intended to make had already been made by previous speakers. He, therefore, simply wished to raise one or two points, as he understood the object of the discussion was more to criticise the method of procedure of the proposed research than to criticise the Report itself. He was quite in accord with Dr. Tilden's opinion that the author had not included in the Report some important investigations on the subject. For instance, in Dr. Percy's work much information is found upon the corrosion of metals, and references were given to the Admiralty investigations on the subject. He suggested that it was advisable to prepare a complete résumé of all the work that had been done in connection with corrosion of non-ferrous metals. Their forefathers had done much work on the subject, although they might not have used modern terms, nevertheless they had made signal efforts to solve the problems, with more or less success. It, therefore, seemed to him that the Committee ought to prepare a résumé of that work before they undertook any experiments. He next wished to refer to the suggested use of external electromotive force mentioned on p. 84. Without going into any details, the use of external electromotive force was likely, in his humble opinion, to lead to trouble in an investigation of the kind contemplated. He suggested that the conditions of experiment should be made as nearly as possible analogous to practical conditions. An external electromotive force would be accidental in practice. On the other hand, the thermo-electric effect referred to by Mr. Philip was intrinsic, and ought to be determined and controlled. In the next place, he wished to suggest that if applied electromotive force is to be employed,

may it not be generated in the experimental apparatus itself, *i.e.* by arranging the latter as a primary battery? Such a condition might occur in practice, through faulty design or misuse of metals.

The PRESIDENT said that he desired to answer the question asked by Mr. Heap with regard to the Corrosion Committee. The Corrosion Committee was formed by the Council at the suggestion of Professor Carpenter. If the members would refer to the Council's Report on p. 4 they would see that the question had been very carefully considered by the Council, which eventually appointed an influential Committee, the names of the members of which were set out in the Report. In reply to Mr. Heap's further question as to what work the Committee had done, the Committee first of all appointed Mr. Bengough as the investigator on their behalf, to accumulate as far as possible all the information hitherto available on the subject of corrosion, and to report to the Committee the result of his investigation. That Mr. Bengough had done, and the result of his work was included in Mr. Bengough's Report to the Committee, which had been read and discussed before the Institute that morning. He thought the members would agree the Report showed that considerable work had been done. It was rather a large inquiry to ask what the Committee would do in the future, and before he could answer the question it would require careful consideration : but, at the moment, the Committee was engaged in carefully considering Mr. Bengough's Report, and in deciding what steps should be taken to carry out his recommendations, or any modifications of them which they might think fit. Beyond that, he was not in a position at the present moment to state what the Committee would do. What it did would depend largely on the result of his application to the members that morning for funds, because it was needless for him to point out that the work of the Committee must be largely governed by the funds at its disposal for the purpose. He hoped that contributors to the fund would not be confined to members of the Institute, but that firms which were considerably interested in the question would also subscribe. Such firms would be circularised and asked to support the work of the Committee. Many firms of good standing would, he had no doubt, be willing to subscribe. It was impossible, however, for him definitely to answer the question as to what the Committee would do in the future.

Mr. BENGOUGH, in reply to the discussion, wrote that he was grateful to Sir William Tilden for his interesting contribution to the discussion on the Report. He agreed that one of the principal objects of the research to be undertaken by the Committee should be to ascertain definitely what substances could set up electrolytic action of the kind described by Sir William Tilden. He noticed with much interest the important difference of opinion which existed between Utheman and Sir William as regards the effect of ferric oxide on the speed of corrosion, and was much obliged for the additional information supplied by the latter with regard to his experiments on the effect of iron in contact with brass and hot sea-water. He quite agreed with Sir William's suggestion

that the conditions obtaining in practice should be imitated as closely as possible in carrying out the main series of experiments.

He wished to express his thanks to Dr. Rosenhain both for his appreciative remarks and for his suggestions. He was particularly interested in the question of crystal size in relation to the position of the pitting of condenser tubes. The simple test with nitric acid suggested by Dr. Rosenhain was certainly a very convenient one, and further investigation might very well show that it was highly suggestive and important. He intended to pay considerable attention to it ; he tendered his thanks to its author.

He was interested in what Mr. Seaton had said with regard to the gauge of condenser tubes. His remarks might possibly throw some light on the opinion of Isherwood and others that thick tubes corroded less quickly than thinner ones, for corrosion troubles seemed to have increased at more than a proportionate rate since the reduction of the gauges. He dared not follow Mr. Seaton in his remarks about steel tubes ; he stood in too much awe of the President's displeasure. He was much interested to hear of Mr. Seaton's experience in never having met with a case of pitting where cast-iron tube plates were used. He would have expected the state of things described, namely, that the plates were corroded and the tubes protected by the resulting electrolytic action ; but if the wooden ferrules insulated the tubes entirely from the iron, as was suggested by Mr. Seaton, that view was not tenable, and the case became very interesting and difficult to explain. He was much indebted to Mr. Seaton for the expression of his opinion that the paper would be appreciated by practical men. He valued that testimony very highly.

Professor Turner referred to some experiments carried out in his laboratory by Mr. Brühl ; he (the writer) hoped that the Committee would have an opportunity in the future of considering those experiments in detail ; he considered that the determination of the electrical conductivity of the green deposit found in corroded tubes was most important. He thanked Professor Turner for his kind expressions about the Report.

Dr. Dunn asked for information regarding the equations given on p. 76, and particularly the second set. The first equation in the second set meant that an atom of metallic copper received two positive charges and passed into solution as a cupric ion. The second that an undissociated molecule of water became oxidised to H_2O_2, which then received two negative charges and passed into solution as two hydroxyl ions. The third meant that two negatively charged hydroxyl ions reacted with two positively charged hydrogen ions to give two molecules of H_2O_2 which are electrically neutral. The net result is that the two hydrogens in the last equation have given up two positive charges to the two copper ions in the first equation. He (the writer) agreed with Dr. Dunn that it was important to carry out the tests in duplicate if funds permitted. He might point out, however, that a considerable number of tubes would be used in each experiment and treated identically ; no results obtained in one or two tubes only would be considered as established.

In reply to Mr. Arnold Philip he would like to deal first with the remark that "the fundamental oversight in the paper was, in his opinion, that sufficient information had not first been collected from the users and manufacturers." Mr. Philip has evidently forgotten the terms of reference from the Committee to the author under which the Report was prepared. These terms were : "It was decided to recommend to the Committee that Mr. G. D. Bengough be invited to prepare, in an honorary capacity, a *summary of the literature* dealing with corrosion of metals." It was subsequently decided to confine attention principally to 70 : 30 brass. The writer would point out that he was not a member of the Committee when these decisions were arrived at, whereas Mr. Philip was ; he does not, therefore, accept any responsibility for the "fundamental oversight" mentioned. He was much interested in Mr. Philip's statement that 90 per cent. of the tubes he had examined were corroded along the bottom of the tubes ; this certainly seemed to point to the conclusion suggested by Mr. Philip. He would point out, however, that Dr. Rosenhain, from his own observation, was not prepared to accept generally a simple explanation of that kind, which only covered certain cases. The writer had in his possession a tube which showed holes at nearly the opposite ends of a diameter. Nevertheless the point was an interesting and important one. He was prepared to admit the possibility of causes 2, 3, 4, 5, and 6 referred to by Mr. Philip. Thermochemical action was also a possible cause ; he was inclined to think, however, pending further investigation, that this was not a very serious cause of corrosion ; calculation would show how extremely minute were the currents carried by, say, the water in a condenser, due to thermochemical action ; he thought there were more powerful factors in accelerating corrosion than this one, and that these should be investigated first. He was inclined to accept the causes enumerated from (8) to (13) as possible causes. He was not quite sure what was meant by (18), unless it referred to Isherwood's suggestion mentioned in the Report.

The writer was much interested in Mr. E. L. Rhead's account of his novel experiments, and hoped to hear of them further in due course when the work was completed. He duly noted Mr. Rhead's opinion that crystal size was an important factor in corrosion ; also his interesting suggestion with regard to what he might call the Isherwood phenomenon. With regard to Mr. Rhead's question as to cavities in condenser tubes, he was unable to answer definitely ; it was, doubtless, possible that they might function in the way indicated by Mr. Rhead ; the writer had, however, examined the interior surfaces of new tubes in a few cases only, and he had not detected such cavities. He was much interested in Mr. Rhead's account of the catalytic action of ferric oxide.

Mr. Heap's question had already been replied to by the President, and therefore needed no further answer.

In reply to Mr. Vaughan Hughes he wished to say that if what he wanted was a Report containing an abstract of every paper on corrosion that had ever been written, as apparently he did, he thought he would meet with trouble when the publication committee was approached. He (the writer) had, while carrying out this commission, read through more than double

the number of papers noticed in any detail in the Report, as well as several volumes devoted to the subject of corrosion. He thought that Mr. Hughes scarcely realised the enormous mass of literature on the subject. He himself considered that selection was quite necessary, but of course any possible selection was open to criticism. With regard to the omission of an account of Dr. Percy's work, he thought that after the pioneer work of Davy the next most striking epoch in the history of corrosion was opened by the work of Tilden; considerations of space had, therefore, determined him to omit the intervening period as less important than the succeeding one. He did not think any work likely to influence the course of future experiments had been omitted. In his reply to Mr. Philip he had indicated his views on the part played by thermochemical phenomena. He agreed of course that in the main series of experiments the conditions obtaining in practice should be reproduced as far as possible.

COMMUNICATIONS.

Mr. F. Johnson, M.Sc. (Swansea), wrote that Mr. Bengough had presented a Report on the subject of corrosion, which was second to none in its completeness and comprehensiveness, notwithstanding that much detail must necessarily have been suppressed in order to produce the Report in its present concise and business-like form.

It was very unfortunate that such great diversity of opinion did exist on the subject of corrosion. Different investigators had employed different methods, which seemed to have led them along widely divergent paths; most probably because those who had worked scientifically had worked in the wrong direction, and those who had worked in the right direction had not worked scientifically.

The author had called attention to the absence, from contributions to discussions on various papers, of experimental detail. He (Mr. Johnson) knew of at least one striking exception, and thought that reference should have been made to it, viz. to the exceedingly practical and useful data provided by Mr. A. Sinclair during the discussion on the Eighth Report to the Alloys Research Committee.

With regard to the casting of brass for condenser tubes, the writer could strongly support the views of Sir G. Muntz and the author, that with ordinarily careful alloying in the casting shop, not the slightest variation in composition should result. Other causes might possibly contribute to variations in the composition of a casting, *e.g.* incomplete removal of dross, unduly prolonged or accidentally intermittent pouring. In such cases, however, the casting would probably fail in the subsequent drawing operations—an almost infallible test. If tubes had withstood the severe treatment imposed by the modern draw-bench, one might safely assume that the caster had performed his share of the work —in so far as mixing and clean pouring was concerned—satisfactorily.

On p. 82, the author suggested that the distribution of impurities

contained in solid solution might be irregular, but the writer thought that this was hardly likely. One would not expect the iron, usually found in 70 : 30 brass condenser tubes, to occur in any other condition but that of solid solution (disregarding, of course, the possibility of mechanically entangled particles of oxide of iron derived from the stirring rod).

In this condition the chances of segregation were exceedingly remote. It was a different matter in the case of lead, which, as was generally understood, existed mainly in the free state at the crystal boundaries. Owing to the peculiar conditions which existed in a tube ingot-mould the casting solidified in a manner which could not be considered as ideal. The outside of the cast cylinder solidified rapidly, due to the chilling influence of the iron of the mould ; the inside of the cylinder would solidify later, being in contact with a material of lower thermal conductivity than iron, viz. the sand core. The last portions of the casting to solidify would be nearer to the core than to the periphery ; hence one might expect the fusible lead to segregate in the same neighbourhood, so that the inner walls of a tube would possibly be richer in lead than the outer walls. The top part of the casting would solidify last, and one might also expect to find more lead at the top than at the bottom. If this segregation did occur, however, it could not be very marked, since the solidifying of a brass cylinder whose walls are only $\frac{1}{2}$-inch or $\frac{3}{4}$-inch thick must be extremely rapid.

Too much attention could not be given to perfecting the internal and external smoothness of the tubes, since any grooves or slight crevices left after drawing would afford easy lodgment for the corrosive agent. Under these conditions the writer strongly favoured Tilden's theory, but was inclined to the belief that basic chlorides corroded electrochemically, not only in the presence of water, but also in the presence of moist air.

He did not think that particles of carbon occurred with any frequency in condenser tubes. Particles of sand or "facing" material might cause internal roughness and lead to the formation of grooves during the drawing process. The actual occurrence of such particles (carbon, sand, or slag) in the finished tube was extremely remote. It was the occurrence of grooves and pits due to their possible initial presence in the casting which were of graver importance.

Boring was a wise safeguard, but even this operation would not ensure freedom from those blemishes which it was possible for a tube to receive during subsequent stages of its manufacture.

The author made no mention of the alloy—

								Per Cent.
Copper	.	.	.	.	.	.	.	70
Zinc	.	.	.	.	.	.	.	29
Tin	.	.	.	.	.	.	.	1

which was largely used by the Admiralty. It would be interesting if data could be furnished regarding the relative resistances to corrosion *in service* of this alloy and of ordinary 70:30 metal. The former is supposed to have a much longer life.

With regard to the employment of spiral iron wire as a protective material for copper, the writer had seen some copper wire, which had been exposed to some form of corrosion in actual service, quite soft and tough and uncorroded. Surrounding it was a fine spiral of iron wire, or rather what had originally been iron wire, but had corroded to a spiral of ferric oxide having a hair-like core of metallic iron.

The various expressions of opinion (p. 52) that electrolytic copper was more corrodible than "ordinary best select" demanded some elaboration.

In the first place, the two terms "electrolytic" and "best select" were very vague. Finished material such as tubes, sheet and wire, prepared by any direct electrolytic method, should be spoken of as "electro-deposited" copper. Copper ingots or finished material, which had been prepared from "cathode" copper after melting and casting, were commonly known as H.C. or high-conductivity ingots, &c. It would be more convenient to call such material "electrolytic" copper, and if it had been cast by the aid of a deoxidising agent, "deoxidised electrolytic" copper.

Thus there might be three distinct variations of pure copper, all possessing high electrical conductivities. Of these, "electro-deposited" material certainly offered the least resistance to corrosion.

Then came the term "best select," under which term all sorts and conditions of copper appeared on the market with provoking frequency, and often to the great discomfiture of the purchaser.

It would take up too much space to discuss here either the various impurities which best select copper might and often did contain, or their varying influences on the copper and on its alloys. It would suffice to say that "best select" copper might contain half-a-dozen different impurities in formidable proportions, or it might be equal in purity to "electrolytic."

So it could not definitely be said whether the lower susceptibility to corrosion of "best select" copper and alloys made from it was really due to the impurities which it contained, or to some other cause.

Disregarding the question of impurities, electro-deposited articles of copper (*e.g.* tubes) were physically different from similar articles which had been manufactured from castings.

In the former case the material might be regarded as a mechanically-built up aggregate of fine metallic particles, cemented together under the influence of the electric current, and of either a burnisher or centrifugal action.

In the latter case the metal had, in solidifying from the molten state, assumed a knitted structure due to dendritic crystallisation. Further, the interlacing dendrites had been "shrunk" together by the natural process of contraction after solidification.

Hence, one would expect greater inter-crystalline adhesion in the latter case. Assuming that the advances of corrosion only operated along inter-crystalline planes, it was possible that the fewer planes there were, the less marked would be the corrosion. From the very nature of the building process whereby electro-deposited material was produced the inter-crystalline planes must be numerically greater than those in cast material.

The possibility of hydrogen being the cause of greater corrodibility in the case of electro-deposited copper, as suggested by the author (p. 81), was a very interesting one. The presence of hydrogen, however, in furnace refined copper was well known, and it seemed to him (Mr. Johnson) that, owing to the property which molten copper possessed of dissolving hydrogen, and of retaining a large proportion after solidification, one might expect to find even more hydrogen present in cast than in electro-deposited copper. Analyses of both for hydrogen contents would be very useful in clearing up this point.

With regard to the figures given by Cowper Coles for copper tubes made by the centrifugal process, viz. 17 tons per square inch, it should be remembered that no mention was made of the mechanical condition of the material. After annealing, the tensile strength would be considerably lowered. Furnace refined, solid-drawn copper tubes would give still higher results, if tested in the hard-drawn condition.

With regard to the influence of cuprous oxide on the rate of corrosion of copper, he (Mr. Johnson) had tested two specimens of rod of the following compositions :—

	No. 1.Per Cent.	No. 2.Per Cent.
Copper	99·59	99·60
Arsenic	0·34	0·34
Oxygen	0·06	nil
Iron	nil	0·04

After immersion (in separate vessels) in equal quantities of a solution of common salt, acidified with hydrochloric acid, he had found that No. 2 had lost a shade more in weight than in No. 1.

No. 1 was a sample of "tough pitch" copper; while No. 2 was a sample from which all oxygen had been eliminated before casting.

Both samples had been subjected to identical treatment in rolling. These results, although not entirely conclusive, certainly pointed towards the *neutrality* of cuprous oxide, if not towards its protective influence.

Mr. Arnold Philip (Portsmouth) wrote that in the original discussion of Mr. Bengough's Report to the Corrosion Committee he had been prevented by the time limit from completing the criticisms which he had felt it desirable to put on record concerning the proposed methods of investigation, and he therefore wished to now make a further contribution.

As far as his experience went, in every case where corrosion of a condenser tube by sea-water had occurred, the sea-water side of the tube had been sufficiently long in use to have become covered with a firmly adherent incrustation of salts deposited from the water under the action of heat; yet, in spite of this fact, it was proposed in this Report that all the tubes should be weighed both before and after the experiments. It was difficult to understand what useful end it was proposed to attain by this procedure. If it was directed to ascertaining the loss in weight of the tubes caused by corrosion, it was clear that the scale deposited from the water must be removed before the final weighing took place, and if it was

proposed to remove the scale from the inside of the tubes by hammering or scraping before cutting them open, then all he could say was that this could only be done at the almost certain risk of so damaging the surface of the metal as to render the proposed subsequent microscopic examination (which examination was, of course, most desirable) quite useless. Whilst if, on the other hand, it was proposed to cut the tubes open before weighing them, the difficulties of attaching any real meaning to the change in weight became greater than ever, due to the danger of loss of metal cuttings and the mixing up of these with the particles of scale chipped from the inside of the tubes.

Then with regard to the "guide tubes," consisting of half sections of condenser tubes contained in glass tubes, he failed to understand how such an arrangement could be of any real value in following the course of the corrosion taking place in the other condenser tubes which were fitted in the condenser in the ordinary manner. The corrosion conditions on such "guide tubes" must be entirely different from the conditions in the ordinary tubes for two very evident reasons. Firstly, the temperature conditions would be quite unlike, because the metal would be separated from the steam by a current of cold sea-water, and also by a badly conducting glass tube; whilst secondly, the scale deposited on the surface of the metal would probably be almost non-existent, or would be very much less than on the surfaces of the normally-fitted tubes.

Both the proposed procedure of weighing the tubes before and after the experiments and the use of "guide tubes" were attempts, but he thought unsatisfactory attempts, to watch or control the course of the corrosion by means other than the microscopic examination of the corroded surfaces and the measurements of the decrease in thickness of the walls of the corroded tubes which could be made at the end of the experiments. If such continuous observation of the tubes was really necessary, he ventured to suggest the adoption of an arrangement of the condenser in such a manner that the steam passed through the tubes and the cooling sea-water flowed outside them, an arrangement which was frequently adopted in practice. This would permit, if desired, of a glass-sided condenser body being used, and would also allow of the removal of the sea-water scale from the outside surface of the tubes at the end of the experiment without any danger of damaging the underlying metal surfaces, and would therefore give to the procedure of weighing the tubes before and after the experiment a much more definite meaning, whilst, if desired, certain tubes could be used as "guide tubes," and their outside surfaces could be kept either partially or entirely free from scale by suitable cleaning during the course of the experiment. Even this arrangement was, however, open to criticism, but he hoped that Committee would carefully consider as to whether the use of the sea-water outside instead of inside the condenser tubes might not prove a more convenient method of arranging the condenser for the purpose of these experiments.

Then there was the question as to the sea-water itself. Undoubtedly the experiment would be started with normal sea-water, but for how long would this normality continue? The flow and reflow of this water

through the condenser tubes would soon alter it very considerably. Air and carbonic anhydride would be driven off, whilst, owing to the deposition of scale in the tubes, the normal constituents of the water would be altered, and the formation of scale would decrease. The action of the salt water in these experiments would therefore certainly be different to its action in a normal sea-water-cooled condenser for three reasons : 1st, what were probably important corroding gases would be absent from the water ; 2nd, due to the removal of these gases and the deposition of scale on the tubes, the water would certainly be different from, and would probably be found to be more alkaline than, normal sea-water ; whilst 3rd, the scale coating on the inside of the tubes would be quite different in its amount from what was formed in the same period under the ordinary conditions of practice, and this would no doubt produce its effect on the corrosion.

The simplest method of obviating these difficulties was, in his opinion, to have the experimental condenser erected at some electrical power or other works, which was so situated that sea-water was normally used for condenser cooling purposes. Many such existed in England, and some probably at Liverpool. The experimental work necessitated by these experiments was really very small whilst the corrosion was actually taking place, and should not require continuous watching. Probably an inspection of the condenser every week would be quite sufficient, if arrangements could be made with the works to supply steam and keep the sea-water running continuously. If this arrangement were in any way feasible it appeared very desirable that it should be adopted even at some additional cost.

He was glad to see that Mr. Bengough recognised the fact that one set of experiments must last a year at least, and he thought if decisive results were obtained in that period of time they might consider themselves fortunate, for his own experience had been that corrosion very rarely or never became at all marked until after two years, and usually—fortunately—a good deal longer. He further considered that all the forty-eight tubes in the experimental condenser should be used in one single experiment, for otherwise no very decisive results were to be looked for. Such an investigation must be to some extent of a statistical nature, and unless a considerable number of tubes were treated similarly at the same time there would be considerable doubts as to the validity of the conclusions arrived at.

When one contemplated the fact that there were many millions of condenser tubes corroding day and night under the action of sea-water cooling, the smallness of an experiment with forty-eight tubes made one realise how great importance was to be attached to the Institute in its official capacity exerting itself to obtain the definite histories of some of these millions of tubes both from the users and from the manufacturers.

He proposed that systematic tests for chlorine in the condensed steam from the experimental condenser should be made throughout the experiments, in order to at once detect the fact that leakage round the ends or through holes corroded in the tubes had occurred.

He trusted that a bibliography of the usual alphabetical form, and dealing with the corrosion of the non-ferrous metals, would be prepared by the Committee, and that this bibliography would be bound up with the Journal. As a starting-point in this scheme, he was hopeful that arrangements could be made by the Council with the Carnegie Library of Pittsburg which would enable the Institute of Metals to bind up with their Journal a copy of the very excellent bibliography of the corrosion of metals and alloys, both ferrous and non-ferrous, which had been published by that Library, and of which a copy had recently been presented to the Institute. The date of this bibliography was July 1909, and it would only be necessary for the Committee to bring this up to date from time to time. Such a bibliography, he felt sure, would be of the very greatest use to all interested in this subject.

In conclusion, he wished to emphasise the fact that the general method which he had advocated for investigating the phenomena of corrosion was merely that usually applied in dealing with functions of several variables, namely, to ascertain if possible all the variables of which corrosion was a function, and then, keeping all but one of these as small and as constant as possible, to cause the remaining variable to alter systematically, and note the corresponding variation in the corrosion thus produced. He hoped that the Committee would in any case very carefully and even elaborately scrutinise all proposals for this experimental work before finally assenting to it being carried out.

Mr. A. E. RICHARDS (Manager of the Constructive Department, Royal Dockyard, Devonport) wrote, referring to the deterioration of Muntz metal in Australian waters (p. 46), that the point was very interesting, but he could not agree with the deduction arrived at, that it might be due to the substitution of brown paper and varnish for felt and Stockholm tar. There had been exactly the same experience in ships of the Royal Navy, not only in the copper sheathing but in the Muntz metal bolts first used in composite ships; that was to say, in vessels with iron frames and wood planking on the bottom. Many of those Muntz metal bolts became absolutely porous, and the zinc worked out of them completely. When broken, solid particles of zinc could be seen separated entirely from the copper. Mr. Farquharson, who was then in charge of the supervision of the manufacture of copper sheathing and the alloys of copper for ship work, overcame that difficulty by the introduction of a little tin into the mixture, and this led up to the introduction of naval brass, which is quite free from any separating-out of the zinc. Referring to his personal observation of the manufacture of copper sheathing, and not from any statement in the Report, Mr. Richards wrote that most of the copper and metal sheets which he had used had been rolled from cast ingots. He had often thought, when watching the rolling of these ingots into sheets, that probably the irregular surface of the ingot might cause an uneven distribution of pressure on the surface when under the rollers, and so produce variations in the hardness of different portions of the surface of the completed sheets. In rolling out a thin copper sheet from thickness to thickness

the operation was rapid, and he was doubtful, if an irregular ingot was rolled, whether a surface of varying hardness would not be produced. It was possible that such variation in hardness might partly account for the pitting or variability of corrosion in different parts of a sheet. In the manufacture of tubes, of course, the ingot was bored out and turned on the outside, which operation secured uniformity of surface and of thickness such as were wanting in the production of metal sheets. Another point, which in his experience had always been noticeable in the corrosion of copper sheathing on ships' bottoms, was that if a sheathed ship remained *stationary* for any time, the corrosion proceeded rapidly. On the other hand, when ships were engaged in performing long voyages, and remained stationary only for short periods, the corrosion of the copper sheathing was as a rule very small. Many ships had proceeded to Australia and back, and returned with their copper sheathing practically free from corrosion.

Mr. BENGOUGH wrote, in reply to the written communications, that he was much obliged to Mr. F. Johnson for his long and interesting communication. He valued his expression of opinion with regard to the distribution of iron, lead, and other impurities in a casting for tube manufacture. He also valued Mr. Johnson's idea that particles of sand, " facing material," &c., would be more likely to act prejudicially by forming grooves and pits in the tubes than by acting as cathodes on their own account. He agreed that exact details of the relative corrodibility of 70 : 30 brass and 70 : 29 : 1 brass would be of great interest. It was generally considered that the latter was much less corrodible than the former, as mentioned by Mr. Johnson, but he knew of no exact comparative figures. He agreed that it would be desirable to use a more precise system of nomenclature for the various kinds of copper, and thought Mr. Johnson's suggestions were excellent ; " best select " was certainly a very vague term, and it would be a considerable step forward if some influential body would take up the question of the nomenclature of non-ferrous metals and alloys. He was not able to follow entirely the paragraph dealing with the building process of electro-deposited metal. He was particularly interested in Mr. Johnson's opinion, backed by details of a particular experiment, that cuprous oxide observed a benevolent neutrality in the matter of corrosion.

In reply to Mr. Arnold Philip's communication, he would state that he was quite unable to follow that gentleman's objection to the weighing of the tubes before and after the corrosion experiment. The results might or might not be any value—he could not say till he had tried ; the labour involved in the matter was quite trifling. He did not propose to cut the tube open before weighing in order to remove scale. He would first weigh them as taken from the condenser ; afterwards he would brush out as much scale as possible with a stiff brush and weigh again. In some cases, of course, the scale would not be removed ; in others very little scale was found. He did not propose to use the weights of the tubes as a means of controlling the experiment as assumed by Mr. Philip. For control he relied on " guide tubes " alone. He was aware that the tem-

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perature conditions in these tubes would be slightly different from those in the others, but the temperature would be lower, and the fault would be on the right side. He entirely disagreed with the suggestion of putting the water on the outside of the tubes ; he considered that this would be a vital mistake. From inquiries he had made he had ascertained that 90 per cent. of all the tubes used in mercantile marine practice were in contact with sea-water on the inside. The proportion was nearly as great in power-station and works practice. The cause of corrosion might be very different when the water was circulated on the outside of the tubes, and he would oppose any suggestion to that effect.

With regard to the change in composition of the sea-water with time, he agreed that small changes might take place. He had proposed that the water should be changed every six weeks ; three weeks would probably be better. In that space of time he did not think any serious changes of composition, due to deposit of scale or other causes, could possibly take place. He did not agree with the plan of placing the apparatus in a works where observation would be carried out by busy people unused to scientific work. Constant and careful observation were essential to the scheme. He agreed with the suggestion that chlorine estimates should be made to detect leakage. He also agreed with the suggestion with regard to a bibliography.

He was much interested in Mr. A. E. Richard's opinion that the substitution of brown paper and varnish for felt and Stockholm tar did not affect the corrosion of rusty metal. He was surprised to learn that solid particles of zinc could be seen separated entirely from the copper in the case of certain rusty metal bolts. He would much like to see them. He was glad to have Mr. Richard's confirmation of the fact of the preservative value of tin in Muntz metal. He was also much interested in the fact brought out by Mr. Richard that corrosion of sheathing was accelerated when the ship was stationary.

SOME PRACTICAL EXPERIENCE WITH CORROSION OF METALS.*

By Engineer Rear-Admiral JOHN T. CORNER, C.B. (late Chief Engineer of Portsmouth Dockyard).

It should be pointed out at the outset that in this paper the writer purposes to limit himself to chiefly giving instances of corrosion which have come under his notice whilst actively engaged as a marine engineer, and to detail some of the practical methods found to be efficacious in dealing with the same.

Some of the causes of corrosion of metals on shipboard are so obscure, and the origin so difficult to trace, that no satisfactory explanation is so far forthcoming. On the other hand, cases have occurred in which the causes operating to produce the effects are clearly recognised and easily dealt with.

The writer has had no personal experience of the trouble which took place through the corrosion of copper and its alloys in the old wooden ships, but that such corrosion did exist is within the knowledge of most of those who have studied the record of such ships. Cases are mentioned of copper sheathing having become corroded in mysterious ways and at unexpected times, and there are reports of the heads of the nails having corroded entirely off, allowing the sheathing to become detached.

There were doubtless at times troubles through corrosion in the bilge and other copper pipes of the old wooden steam-ships of war, but as a rule these appear to have been of minor importance ; and in many ships the chief anxiety the engineers had concerning the pipes was to keep them in a bright and burnished condition so as to pass the captain's weekly inspection, at which the array of copper piping in the bilges was often one of the show sights of the ship.

With the introduction of iron for shipbuilding purposes the

conditions were different, for it was soon found necessary to insulate as well as protect the copper pipes in or near the bilges—not, however, for their own welfare so much as for the sake of the adjacent plates and angles, which, when not so treated, were found to be adversely affected by contact, owing to the galvanic action set up between the metal pipes and the iron plating by the bilge water.

There were many instances in which very considerable trouble was caused. Among them may be mentioned the case of the troopship *Megaera*, which vessel had to be beached at St. Paul's Island about 1869 to prevent her sinking. It came out in the subsequent inquiry that among other defects in this ship, there was a serious one due to a copper strainer fitted to a bilge suction pipe in a remote part of the ship. The action set up by it was sufficient to eat right through the plates, and so admit water to such an extent that the ship had to be run ashore to save the crew.

As far as can be ascertained, the pipes themselves in iron ships were no more affected than those in wooden ships, probably not so much; and it was not until at or about the time of a great change in the internal economy of men-of-war that serious and persistent trouble through the corrosion of copper pipes began to be manifest and felt. This change was the introduction of the electric light on shipboard.

The writer's first experience of the insidious corrosion of copper pipes occurred in a ship which had recently been fitted with an electrical installation for working searchlights. During a commission of over three years there were, as far as can be remembered, only two pipes which seriously suffered from corrosion; both were water pipes, and both were eaten right through in small holes which had the appearance of having been punched, and it is noteworthy that each of these pipes was in the immediate vicinity of an electric lead to a search-light—the one forward and the other aft. The whole business was after all but a minor affair, and consequently very little notice was taken of it; it was only years afterwards when trying to assign a cause for similar trouble in various other ships that the previous experience was recalled to throw light on an obscure question.

There is no doubt whatever that the time of the introduction of the electric light in naval ships synchronised with a considerable increase in the corrosion of the copper and metal pipes and fittings; and as the parts affected were chiefly water fittings, the increased steam pressures which came at or near this period, and which might have been suspected as one of the causes, can be now quite absolved from any share or part of the trouble.

Sometimes pipes would be found eaten nearly, and in some quite, through in a very short period; moreover, the replaced parts often became similarly affected even when different brands or qualities of copper or brass were used. Sometimes the pipes were eaten in holes having sharp, clean-cut edges, as though punched; sometimes parts were pitted and honeycombed over a considerable area of surface; while in other examples the metal was nibbled out in such a way as almost to suggest the presence of rodents or microbes.

As regards the source of this trouble, some engineers for the reasons above stated were inclined to attribute it to electrical action due to the leakage from the mains, which was often so great as to allow electricity to permeate the whole ship. It must be admitted now that some of the earlier electrical installations on shipboard were a long way from perfect, inasmuch as leakage in some cases was sufficient to turn the ships themselves into storage batteries. Others attributed these defects in the copper pipes to induced currents set up in different parts of the ship by the currents in the electrical mains. But nothing definite could be proved, and those then dealing with the electrical plant disclaimed all responsibility for the trouble, and in fact sometimes expressing the opinion that the currents they used could hurt nothing and cause trouble to nobody.

It was also further suggested that the action might be due to mere chemical causes, but here again the responsibility for this was disclaimed by those concerned, the corrosion being put down by them to mechanical rather than chemical action; and there was certainly some ground for the contention, seeing that corrosion in pipes generally occurred at or near bends or branches; also very extensive corrosion often occurred

on the bronze propeller blades, especially at the forward side where there was little likelihood of extensive action, electrical or chemical, but abundance of the mechanical kind.

It is very probable that a certain amount of chemical action was first induced by galvanic action, and the erosion caused by the friction of the water, which washed away the results of the chemical action, left the clean surface exposed to further and similar action. This explanation, however, would not fully apply to cases where clean-cut holes were found in the pipes, condenser tubes, &c.; these results were probably due to want of homogeneity in the composition of the metal, the galvanic and chemical action finding out the weakest places. It would also appear that the presence of air and moisture together largely influences the extent of the corrosion of these metals as of iron, and in a measure helps to explain the pitting on the forward sides of the propeller blades, where the partial vacuum formed by the motion of the screws causes air to be drawn from the surrounding sea-water, which assists the corrosive action.

It was also suggested that the corrosion might be due to the use of copper of too pure a quality; and in this connection it may be noted that some locomotive engineers specify for about $\frac{1}{2}$ per cent. of arsenic in the copper fire-box plates, as a preventive against corrosion. So there really may have been something in this suggestion, seeing that pure electrolytic copper was beginning to be used at or about the time referred to.

But whatever may have been the causes, the pressing business of the day was to discover the cure of the complaint: the prevention of the corrosion, which affected most of the water pipes, including the condenser tubes of many ships, was what all aimed at. As regards the latter, it is understood there was not much general corrosion of the tubes in iron condensers. No doubt there have been, as there still are, some instances in which the tubes of iron condensers have given considerable trouble through various causes, some of which were foul circulating water, defective materials, excessive vibration through indirect local pressure, such as

the direct impinging of the steam or circulating water on the tubes, &c.; but as regards the corrosion under consideration, it may be stated generally that it is certainly much less in condensers with iron shells than in those with brass shells.

One special case of an iron condenser which came under the writer's notice was interesting and unique, and may be mentioned here:—A ship with a cast-iron condenser, with circulating water outside the tubes, had been running for several years with a set of tubes which had given no trouble whatever. The ship unfortunately got ashore on a sandbank, and in the getting off stirred up the sand so much as to get a large quantity deposited in the condenser on the circulating sides. On returning to port for overhaul and repairs, the tubes were taken out to get rid of the sand. This afforded the opportunity for examining and attending to the inside of the condenser shells. They were cleaned by being chipped and scraped, and finally given a good coating of red-lead paint. Shortly after the ship resumed service, the condenser tubes, which up to then had given no trouble, began to go to such an extent that the ship had to be again laid up for the complete re-tubing of the condensers. When this was done, the red-lead paint was all removed, after which no further trouble with the tubes was experienced. This result clearly showed that the brass tubes were being protected when the iron shells were bare, but when covered with lead paint a corrosive action on the tubes manifested itself.

Another case of the protection afforded by iron may be mentioned:—In a certain ship, one particular pipe conveying circulating water was repeatedly in trouble through corrosion. This pipe would be found badly eaten away at a bend. It was taken down, patched, and replaced time after time, but the corrosion still went on and continued. The chief engineer then resorted to the following expedient. He sweated a lump of copper on the outside of the pipe, so as to provide material for a screwed hole, through which a large iron bolt, about $1\frac{1}{2}$ inch diameter, was fitted so that the point protruded; and no further trouble was experienced with this pipe, the bolt being screwed further in as the point became eaten away, and being entirely renewed when necessary.

These two examples appear to indicate that the presence of sufficient bare or unprotected iron in perfect metallic contact with the system strongly counteracts the corrosion of the copper or brass; the chemical or electrical or mechanical action, whichever it may be, solely or jointly, being entirely expended on the iron. It is therefore by the free use of iron or steel that it is considered the best protection of the copper or alloy pipes is provided.

Before resorting, however, to such free use of iron, various other means were tried in different ships. One method was to coat the insides of the pipes with marine glue, another to use plumber's solder or tinman's solder as an internal coating. Special alloys containing aluminium were tried. Zinc slabs and blocks were used, as also zinc bars let in amongst the condenser tubes; and though some of these expedients effected a certain amount of good, it is considered that the present practice has more to recommend it than any of them, and that is the insertion of short iron lengths of pipe in runs of water pipes which can be easily removed and replaced; and further, the use of iron or steel doors for brass condensers with iron rods and plates in and about the tubes is very effective as a protection to the tubes and plates.

In some warships of late years the condenser barrels are made of steel. Of course in this latter case there is the possibility of a certain amount of corrosion in the condensers themselves, but as this is only to be expected on the water-side, it should not be difficult to deal with—the design of the condenser being such as to admit of the easy replacement of parts likely to be affected, and provision being made for zinc protectors as in boilers.

It is considered more than probable that the reason why iron is found on the whole to be more efficient as a protective than zinc, is that with the former better metallic contact is assured and maintained, and perfect metallic contact is undoubtedly an absolute necessity.

Respecting the corrosion on propeller blades, it is not known to the writer whether iron has been tried as a protection against corrosion; but he would suggest for consideration that if easily renewable plugs of iron could be put at the

parts of the propeller blades where corrosion is likely to occur, they might lead to a marked difference in the extent of the pitting, for it may possibly be found that so long as there is iron in the immediate vicinity sufficient to absorb the corrosive action, the bronze will be entirely protected.

DISCUSSION.

Mr. A. E. SEATON, Member of Council, in opening the discussion on Admiral Corner's paper, said that he was afraid, in some remarks he made on Mr. Bengough's paper, he was guilty of a small sort of treason, inasmuch as he had dragged into the discussion a question of *steel* pipes. He had been pardoned, however, by the President, but nevertheless he intended again to run a little risk. The author of the present paper, Admiral Corner, was here as a witness to give evidence on the important question before the Institute ; he thought all such evidence as could be obtained on the subject would be of supreme importance to the Committee, whose composition and functions had just been referred to by the President. The question of corrosion was a very old one, even older than Mr. Bengough stated in his paper, because it was related on the authority of no less a person than Mr. Samuel Pepys that, in Charles II.'s reign, trouble was experienced with ships sheathed, as they then were, with lead. Complaint was made as to the effect on the iron fastenings of the ships ; eventually the use of lead as a sheathing was abandoned. Later on copper sheathing was adopted, and with the copper sheathing he presumed came copper fastenings, because he could not conceive that, after giving up lead sheathing, anybody would put copper on to an iron-fastened ship. But there was one thing the Committee had failed to take cognisance of, namely, the instances in which Muntz metal was seriously affected without showing any visible sign of it. He once saw some Muntz metal bolts that had been taken from a composite ship, *i.e.* a ship having a steel frame, with wooden planking fastened to the ribs of the ship by brass screw bolts with a nut inside. The ship was then sheathed with copper, with paper or felt superimposed. That ship unfortunately went ashore on the Humber and became a wreck, and was broken up and the materials sold. The copper was all right and quite usable, but the Muntz metal was worth nothing at all. The report he received from the foreman brassmoulder was that the Muntz metal would not melt, for, although the bolts looked quite as good as on the day they were made, with a small hammer they could be broken into pieces : the fractures presented were of a bright brick-red appearance, and more in the nature of chalk than metal. Now there was no outward and visible sign of that condition of things, otherwise his people would not have bought it. He had not noticed any allusion to that state of degradation in the Report. The author had given some instances of copper corrosion that had come under his notice. He could supplement them by others. For example, copper sheathing was very quickly destroyed on the West Coast of Africa, especially on ships cruising in the neighbourhood of the great rivers—the Niger in particular. The same thing had been observed many years ago on the inlet and discharge pipes on ships trading between Liverpool and Alexandria ; this was attributed to the stagnant water in the harbour at Alexandria. The author had pointed out that the corrosion in one or two cases to which he had called attention was

coincident with fitting the electric light. That reminded him of another instance, where, in the Mediterranean squadron, there was a ship that suffered severely in its inlet and discharge pipes; they had frequently to be mended and sometimes to be replaced; whereas, in the case of a sister ship, fitted with machinery made by the same builder, those defects were not present. The officials were very much puzzled, and eventually, as the ship with the good pipes had to remain in the harbour for some time for repairs, they decided to transfer the pipes from her to the other ship, thinking that the cause was due to something in the copper. But again the defects manifested themselves, so they had to come to the conclusion that some other reason existed for the defects. After a while it occurred to some one that one ship had an electric light installation and the other had not. In those days the naval ships were fitted out on the single wire system, so that the return current was through the ship's metal work. Now, whether that caused or intensified the corrosive action or not he did not know; he simply related it as a little piece of evidence. It was true it was not legal evidence, because it was hearsay and not his own knowledge; but the veracity of the authority from whom he obtained the information was unimpeachable, and the official had no reason to give him the information except as a fact. The author had referred to the question of the corrosion of the backs of propeller blades. It was well known that on cast iron and steel propellers it was very intense; he had never observed whether it was so with bronze propellers or not, but the author assured him it was so. He thought the author was probably right, that after all there was some corrosive action by sea-water that was intensified by admixture with air. He knew that very often in the neighbourhood of the propeller the action on the stern of the ship was very severe. It used to be thought that that was due to the presence of the big bronze screw, but it might be due also to the gaseous nature of the water. He was sure the members would agree with him that the testimony the author had given, coming as it did from such a high source, was of very great value to them, and he hoped the paper would be a forerunner of many others of a similar nature from the same quarter.

Professor T. TURNER, M.Sc., Honorary Treasurer, said he was very much interested in the statement made on p. 117 with regard to the effect obtained with stray current systems, namely, that the pipes were sometimes eaten into holes, with sharp, clean-cut edges, as though they were punctured. That corrosion was entirely different from the effect obtained with a small difference of electromotive force or a slight difference of potential due to a general leakage. Cases had come under his notice in which a metal pipe up to nearly $\frac{1}{4}$ inch thick had been eaten through in places with perfectly sharp edges, as though it had been punched. Any one who had seen that kind of corrosion side by side with tubercular corrosion or general corrosion would see at once that it was an entirely different effect. He had not been able to ascertain the cause of that effect, but he was inclined to think that it was present in cases where a leakage was obtained through a non-conducting coat in

some form. For instance. if a current leaked through a covered wire into a pipe : or conversely, supposing there was mud, or earth, or oxide round the metal, and the current leaked in through one place, the metal was not melted, but it was actually removed bodily. The result was that a perfectly definite hole was obtained, as though the metal had been bored through with a tool, although it was not usually quite circular. It was usually of a lozenge or elliptical shape, with perfectly definite edges, and there was no gradual thinning away as in other cases. It was just as well to emphasise that point in connection with corrosion, because it referred to another kind of electrical action altogether, in which apparently the current entered at a definite place and left in the immediate vicinity of the point at which it entered.

Mr. Arnold Philip (Portsmouth) said the paper represented a record, from the consumers' and manufacturers' point of view, of defects which had been observed in the actual use of metals or alloys, and it was of great importance that the Institute should obtain papers which gave information of this character, because both the consumer and the manufacturer came across a very large number of such corrosion effects. One point came out very strongly in the paper, namely, that a real protective effect was produced, due to the presence of iron. For instance, in a steel-cased condenser no trouble was experienced at all from corrosion of the brass tubes, and when steel doors were put on to another condenser the same was found to be the case. That struck him as being a very valuable piece of evidence, which was still further accentuated by the fact that directly the steel casing in the first example was coated with lead paint the protection disappeared and corrosion troubles began, *i.e.* one of the means of getting rid of corrosion was there very strongly emphasised. He believed that a great deal of valuable information of such a nature could be obtained, not only from the manufacturers but from the users, such as big steamship companies. Admiral Oram had been good enough to tell him that he would be very glad to exert his influence in obtaining permission to use the Admiralty Records of cases of corrosion ; and if the Corrosion Committee of the Institute or the Institute itself would ask for that information from the Admiralty he had no doubt it would be supplied. He felt convinced that much assistance would be gained by the Corrosion Committee if requests for such information were sent round to users generally, together with a schedule of particulars concerning which information was desired, and of directions for the assistance of engineers who were investigating such cases. They might ask, of the engineers for instance, that the lower side of a faulty tube in a condenser should always be marked before the tube was withdrawn, and that it should be stated whether the sea-water passed through the inside of the tube or outside, and whether the tubes were horizontal or vertical, because one of the causes of corrosion which had been mentioned could apparently be largely cured by using vertical tubes ; and such an arrangement of tubes had been used in the naval service. Other questions which might be asked were as to the character and amount of the scale formed on condenser tubes ; also as to the

precise localisation of the corrosion ; as to where the steam or sea-water entered the tubes and where it left ; as to whether the corrosion was observed along the side, or the bottom, or the top of the tubes ; in fact, they should endeavour to get as precise a natural history of each case as possible. Such details were often difficult to obtain. Engineers were generally extremely busy men, and had great difficulty in running their jobs in the time available, so that they had not much left in the rush of work to deal with such questions. But if such a schedule of queries could be sent round from an authoritative body such as the Institute, he felt sure that in a large number of cases the engineers dealing with the matter would avail themselves of the opportunity of putting the facts on record, and the advantage of definite reports on particular cases of corrosion would be thus secured.

Mr. T. VAUGHAN HUGHES, Assoc.R.S.M. (Birmingham), desired to make a few observations in regard to the electric action which was noticed in the early days of shiplighting, to which reference had been made by the author of the paper. It so happened that he was involved in some of the troubles of the "good old days" when the hulls of sea-going vessels formed the return circuits of an electric lighting installation. One of his great reasons for suggesting the abandonment of external source of electromotive force, other than generated on the apparatus itself, to the Corrosion Committee, was the experience he gained of the corrosive action of minute currents of electricity on the hulls and contents of ships. Some years ago it was his province to investigate for one of the local authorities in the Midlands the wholesale destruction of lead piping in an area abutting an electric supply generating station. The lead piping was of a particularly solid type, suited to the extra high-water pressure service in the district. The metal of the pipes was examined for impurities likely to cause nuclei for corrosion. There was no ground for complaint in that direction. The form of corrosion resembled that described by the author—hollows more or less circular in the pipe, and in general like punched holes. His investigations proved that the affected area was permeated by leakage currents of electricity. These were stopped, and the trouble ceased. This cause of corrosion was clearly due to an external source of electromotive force complicated by the presence of street-gas and electric light conduits and water mains, the pipes acting as collectors of stray currents.

Admiral CORNER, in reply, said he was very much gratified at the kind way in which the members had received his paper. When he found that it was to be read immediately after the Report of the Corrosion Committee he was reminded of what sometimes comes after the Lord Mayor's Show ; but felt somewhat consoled by what the genial Secretary had told him when inviting him to write a paper for the meeting—that he only wanted a few practical points and nothing very scientific, because the members of the Institute were chock-full of science already ! He accordingly put down a few practical remarks, which had raised a discussion which he very much appreciated, and

in that respect he thought that Mr. Shaw Scott's prognostications had been amply justified. He had not put forward any definite view as to what the corrosion was caused by; he simply discussed in his paper what steps should be taken to stop it, because that was the important consideration from his point of view. With that lead the Corrosion Committee might be able to develop this view in a particular direction, and go back from the cure to ascertain the cause. With regard to the remarks Mr. Seaton made referring to corrosion in the brass tubes of boilers, it was a very long time since he had anything to do with brass tubes in boilers. When such tubes were used it was not a case of corrosion at all, but of the tubes wearing right out. It occurred to him that brass tubes in a boiler were in the same position as brass tubes in an iron condenser. As far as he knew there was no legitimate corrosion of tubes in iron condensers, the only corrosion which he had experienced in such cases being traceable to some outside cause, such as the water going in too much concentrated on particular tubes, or to air-pockets. None of the mysterious corrosion that he had referred to in part of his paper was experienced in those cases. He was very glad that Professor Turner had referred to the question of the holes being cleanly punched, because that effect was very observable in many cases. The holes frequently had the appearance of having been actually punched out by a sharp instrument. The effect might be accounted for by a different composition of the tube at that particular part, which was influenced by electric action either generated by those conditions or by stray currents from the ship seizing on those weak patches in the pipes. The point he had endeavoured to make in the paper was that iron was the best cure for corrosion—the reason, he believed, being that iron could be kept in a more perfect metallic contact and by having its surfaces exposed longer than the zinc. In conclusion, he thanked the members very much indeed for the kind attention they had given to his paper.

The PRESIDENT said that *apropos* of Admiral Corner's interesting remarks on the question of corrosion, it would give him much pleasure to send to the Pathological Museum of the Institute samples of a copper bilge pipe which he had returned to him some years ago as a bad pipe.* The pipe was eaten in a honeycomb form on the whole of one side, and, as practical tubemakers often found, it occurred at a very sharp bend in the pipe. It might be worth while their scientific friends considering the possibility of accumulated air at the corner of the pipe having some influence on the question of corrosion.

* [This pipe is now in the Museum at Caxton House.—ED.]

A NEW CRITICAL POINT IN COPPER-ZINC ALLOYS: ITS INTERPRETATION AND INFLUENCE ON THEIR PROPERTIES.*

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WITH AN APPENDIX ON

THE NATURE OF SOLID SOLUTIONS

BY C. A. EDWARDS, M.SC.

1. INTRODUCTION.

IN the year 1897 the late Sir William Roberts-Austen, K.C.B., F.R.S., published the complete freezing-point curve of the copper-zinc alloys ([1]). In his diagram, which is reproduced in Fig. 1, certain thermal changes represented by the horizontal lines bB, cC, dD, eE, and $e''e'$ were included. These were interpreted by him as evidences of the presence of eutectics at these temperatures.† This diagram was the first attempt to construct what would in present-day phraseology be called the Equilibrium Diagram of the Copper-Zinc system.

For the purpose of the following paper the authors wish to direct attention to the evidence for the existence of the line $e''e'$. This horizontal indicates a thermal change at about 470° C., occurring in alloys containing from 76 to 46 per cent. of copper. An inspection of the curves on Plate II. of Roberts-Austen's paper, which constitute the experimental evidence for the thermal inversion, and which were obtained

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* Read at Annual General Meeting, London, January 18, 1911.

† Evidence for the horizontal line, nN, was recorded in Roberts-Austen's curves, but did not attract his attention. It was added by E. S. Shepherd in 1904.

by the photographic recording pyrometer, permits of the following conclusions being drawn:—

1. The thermal change recorded was very small, except in two cases.
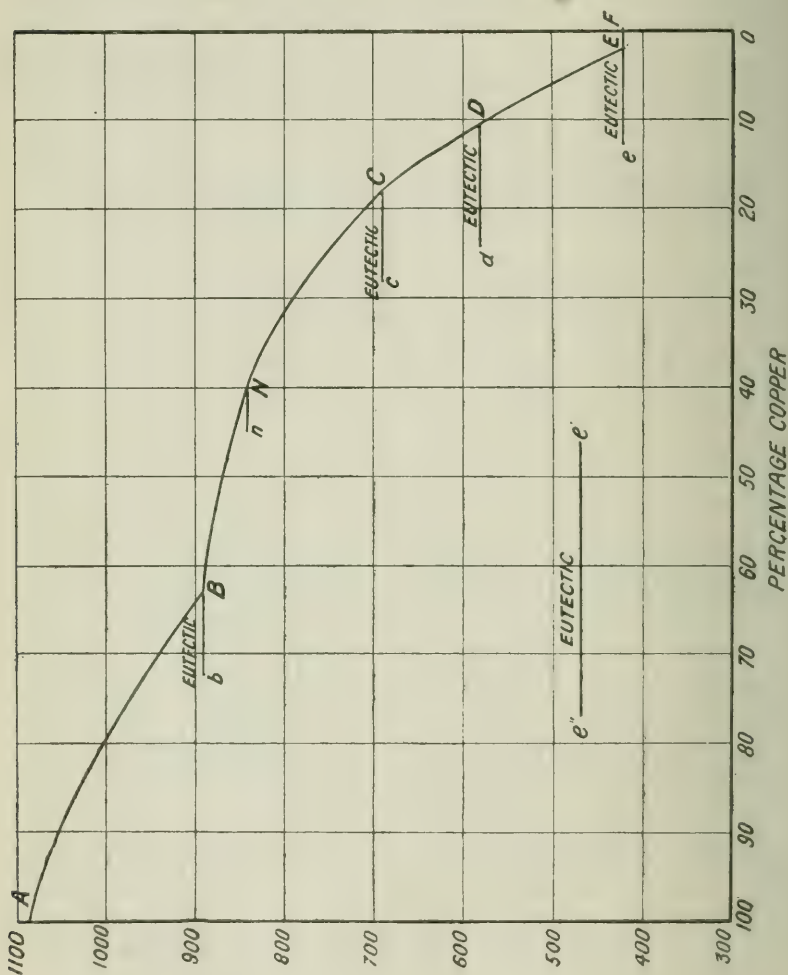
Fig. 1.

2. It was only recorded in ten out of the seventeen alloys examined in this range, as is shown in the following table obtained from Table VIII. in the Alloys Report:—

TABLE I.

Composition.		Temperature of $e''e'$ change.
Copper.	Zinc.	
Per Cent.	Per Cent.	
75·4	24·6	473° C.
71·7	28·3	absent
70·9	29·1	absent
68·6	31·4	450° C.
66·4	33·6	absent
66·2	33·8	absent
63·0	37·0	absent
62·6	37·4	450° C.
59·7	40·3	absent
59·7	40·3	460° C.
59·6	40·4	450° C.
52·1	47·9	463° C.
50·2	49·8	absent
48·1	51·9	460° C.
47·4	52·6	470° C.
47·0	53·0	462° C.
45·8	54·2	470° C.

3. The irregularities were much more marked in the first seven alloys, which, as is now known, contain only the α constituent, than in the last ten, which all contain β, and with two exceptions showed the thermal change.

Although Roberts-Austen regarded $e''e'$ as evidence of a eutectic change, he did not find any support for this view in his study of the structures of the alloys in this range, and he does not appear to have thought of any alternative interpretation of this thermal change. Later researches have shown that the copper-zinc system contains no eutectics.

At a later date E. S. Shepherd ([2]) made a careful determination of the constitution of this series of alloys, and published the first complete equilibrium diagram of the system, which is now generally accepted as correct. This diagram is reproduced in Fig. 2. In regard to the line $e''e'$, he says (page 421): "We are not able to verify his"—*i.e.* Roberts-Austen's—"observations as to the existence of the line $e''e'$. We made repeated records of the cooling curves of alloys ranging in composition between 50 and 75 per cent. of copper without finding such a heat change in any case.

These records were made with the full scale of the pyrometer magnified, so that the range 400° to 550° covered the full breadth of the photographic plate, *i.e.* 28 cm. We have
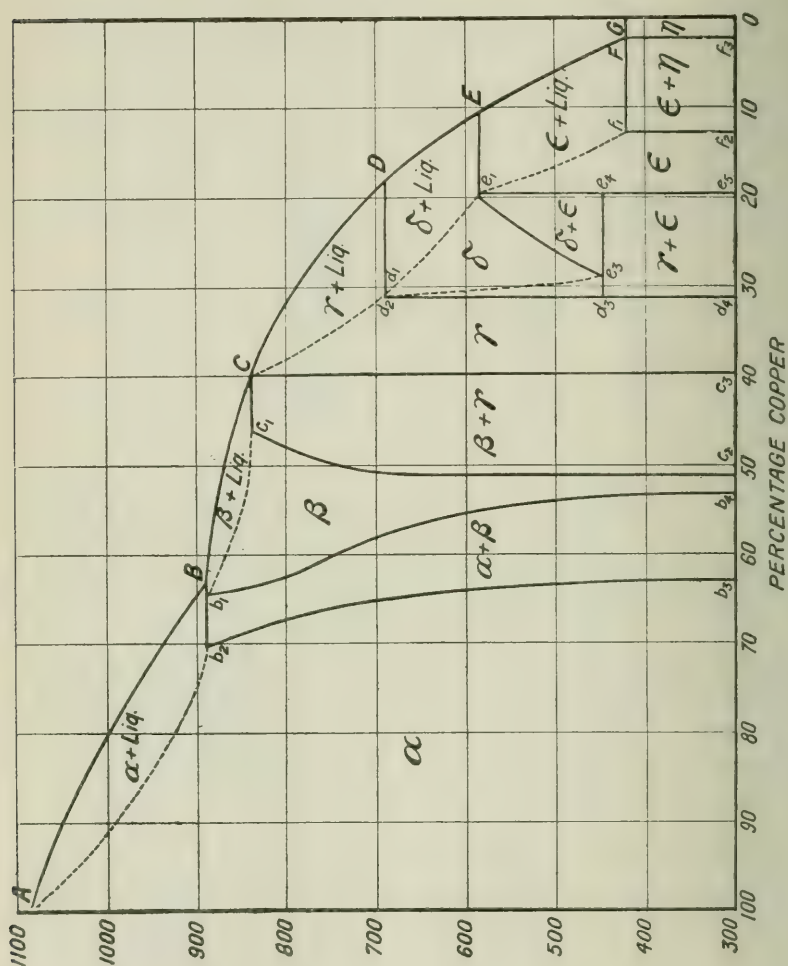
FIG. 2.

also made tests by annealing ingots above and below 470° and quenching, Such ingots show not the slightest change of structure. The temperatures chosen were 400° and 500° C. It follows therefore that the curve *e″e′* is due to

experimental error, possibly to the sticking of the pyrometer record."

In 1908 Tafel ([3]) published an equilibrium diagram of the system which in all essentials confirmed that given by Shepherd. He also made special tests to determine whether the line $e''e'$ was real or not. He found no evidence for its existence, and concluded, though with more hesitation than Shepherd, that " it was apparently based upon an experimental error." This conclusion is accepted by Bornemann in his critical review of the equilibrium diagrams of the system ([4]).

Nevertheless, the experiments described in the following paper show that there is a thermal inversion at about 470° C. over a considerable part of the range of composition covered by the horizontal $e''e'$—in other words, that Roberts-Austen was substantially right, and his critics (Shepherd and Tafel) were wrong.

2. The Evidence for the Thermal Inversion at 470° C.

From their knowledge of the equilibrium diagrams of the copper-aluminium and copper-tin systems, the authors considered it likely, in spite of the conclusions of Shepherd and Tafel, that the copper-zinc alloys containing the β constituent—*i.e.* those containing from about 63 to 40 per cent. of copper—would show a critical point at or about 500° C. In order to test this view, heating and cooling curves of four alloys, having the following compositions, were taken by the differential method ([5]):—

Table II.

| Alloy No. | Composition. | | Constituents. |
	Percentage Copper.	Percentage Zinc.	
1	63·31	36·69	α
2	54·20	45·80	$\alpha + \beta$
3	49·80	50·20	β
4	46·13	53·87	$\beta + \gamma$

The results, which have been plotted in the form of derived differential curves as recommended by Dr. W. Rosenhain ([6]), are shown in Figs. 3–6. It will be seen that the curves of No. 1 alloy, which is almost pure α, containing only minute traces of β, are perfectly smooth, and show no evidence of any thermal change between 670° and 330° C. On the other hand, the curves of Nos. 2, 3, 4, all of which contain a large proportion of β, each show a marked critical point both on heating and cooling at or about 470°.

The cooling curve of No. 2 alloy $(\alpha + \beta)$ shows two arrests— (1) a very small one at about 600° C., which may be caused by the separation of α along the line $b_1 b_4$, shown in Shepherd's diagram ; (2) a very distinct one between 470° and 457°.

The cooling curve of No. 3 alloy (β containing a trace of γ) also shows two arrests—(1) A very small one at about 500°; (2) a pronounced one between 470° and 457°. This arrest is larger than the corresponding one in No. 2.

The cooling curve of No. 4 alloy $(\beta + \gamma)$ shows an arrest between 470° and 445°. This is smaller than those in Nos. 2 and 3, and is more drawn out. The heating curves of these three alloys are very similar and show a retardation, whose beginning is not well marked, but which attains its maximum at 470° C.

That there is a critical point at about 470° in those alloys containing from about 63 to 40 per cent. of copper, is clearly shown by the foregoing curves ; and although these limits do not agree exactly with those given in Roberts-Austen's diagram, the temperature at which the inversion occurs is the same in both cases.

3. Interpretation of the Thermal Inversion.

Now it has been shown by Shepherd that the copper-zinc system contains no eutectics. It is therefore a matter of considerable theoretical and possibly practical interest to define the constitutional change that must of necessity occur in these alloys at the temperature indicated by the critical point. Since the latter occurs in alloys 2, 3, and 4, which, according to Shepherd's diagram, consist of $\alpha + \beta$, β and $\beta + \gamma$
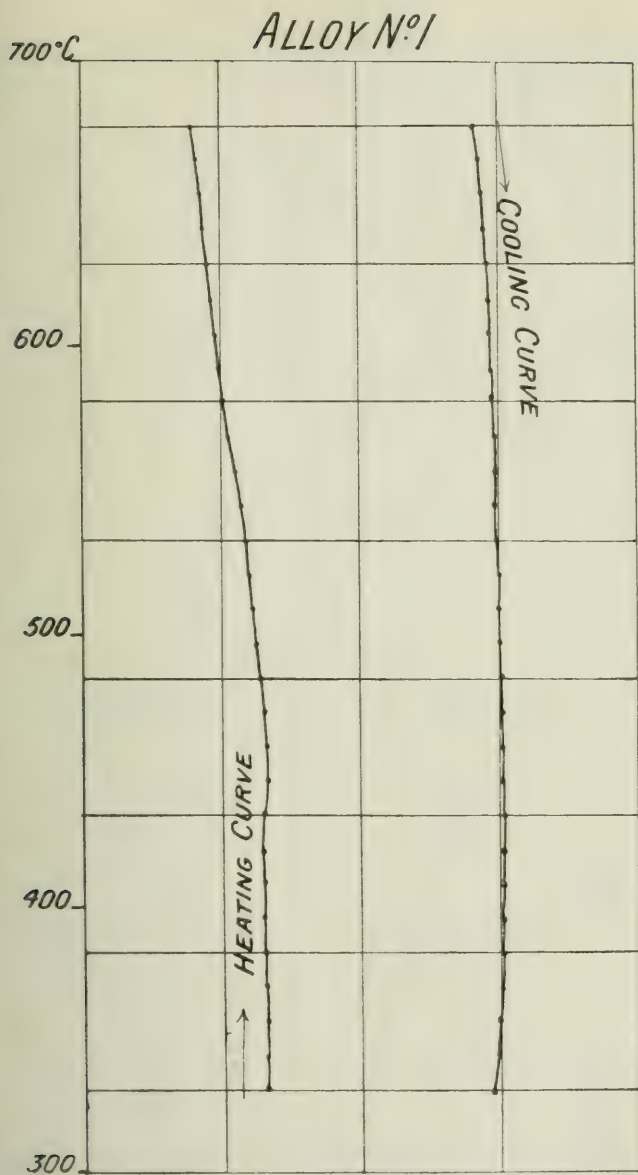
FIG. 3.—Curves of the α constituent.
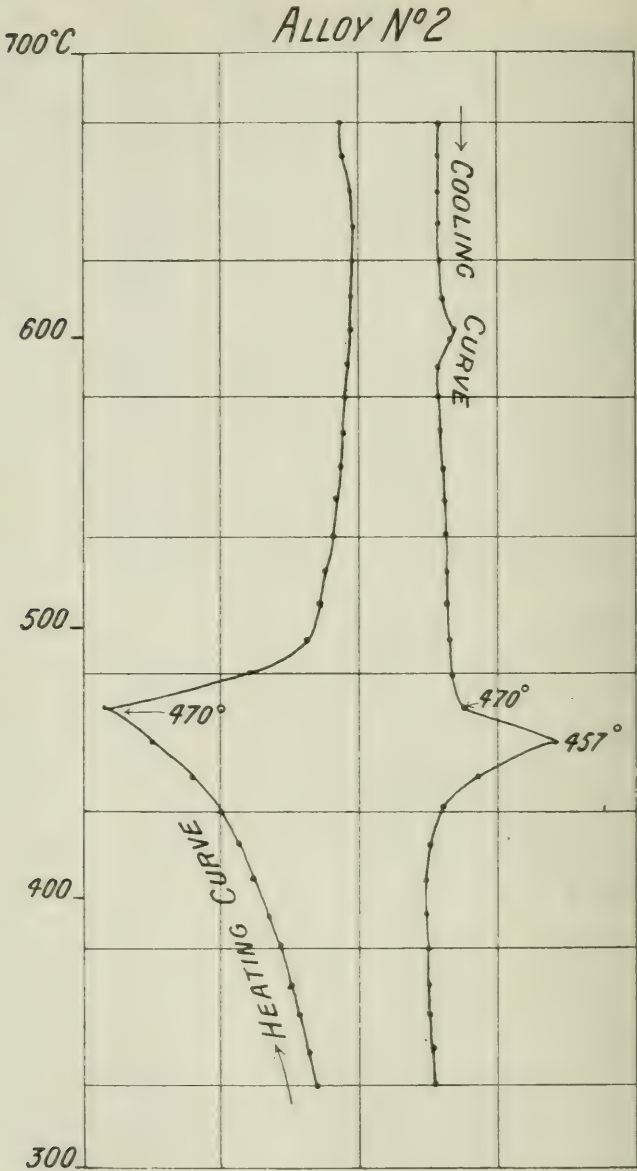
Fig. 4.—Curves of the $\alpha + \beta$ constituents.
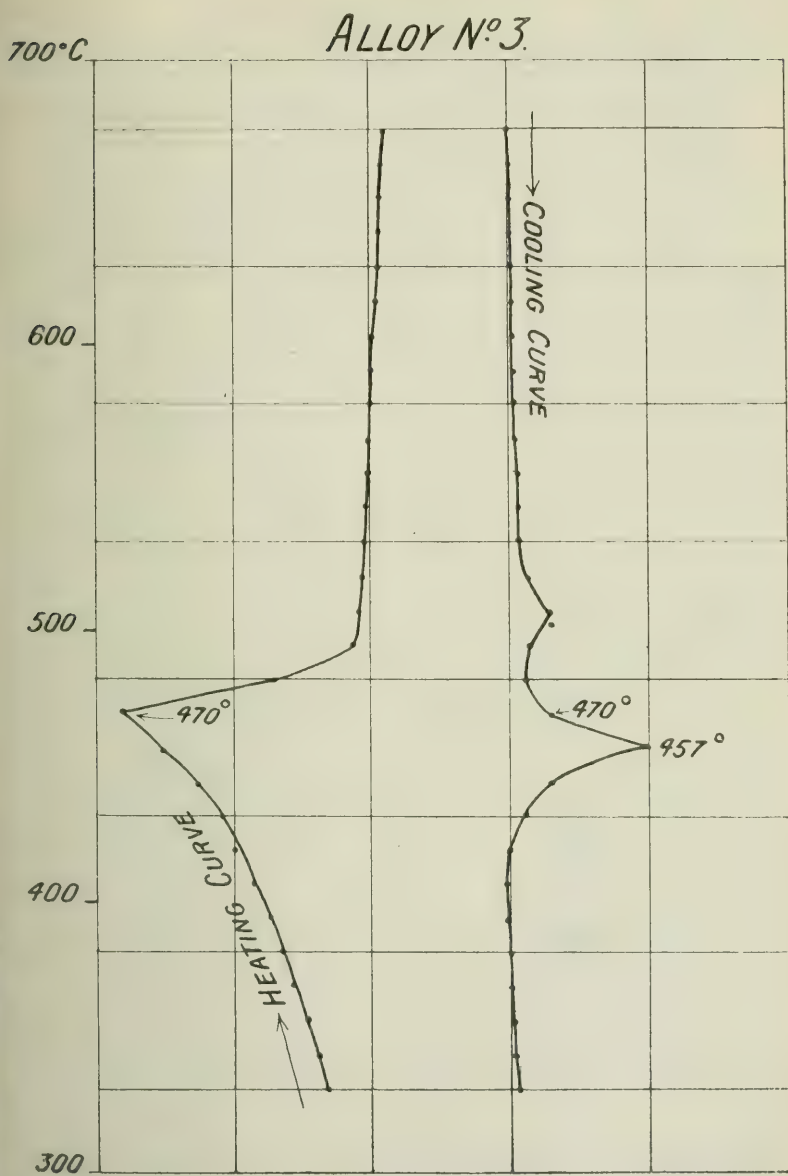
FIG. 5.—Curves of the β constituent.
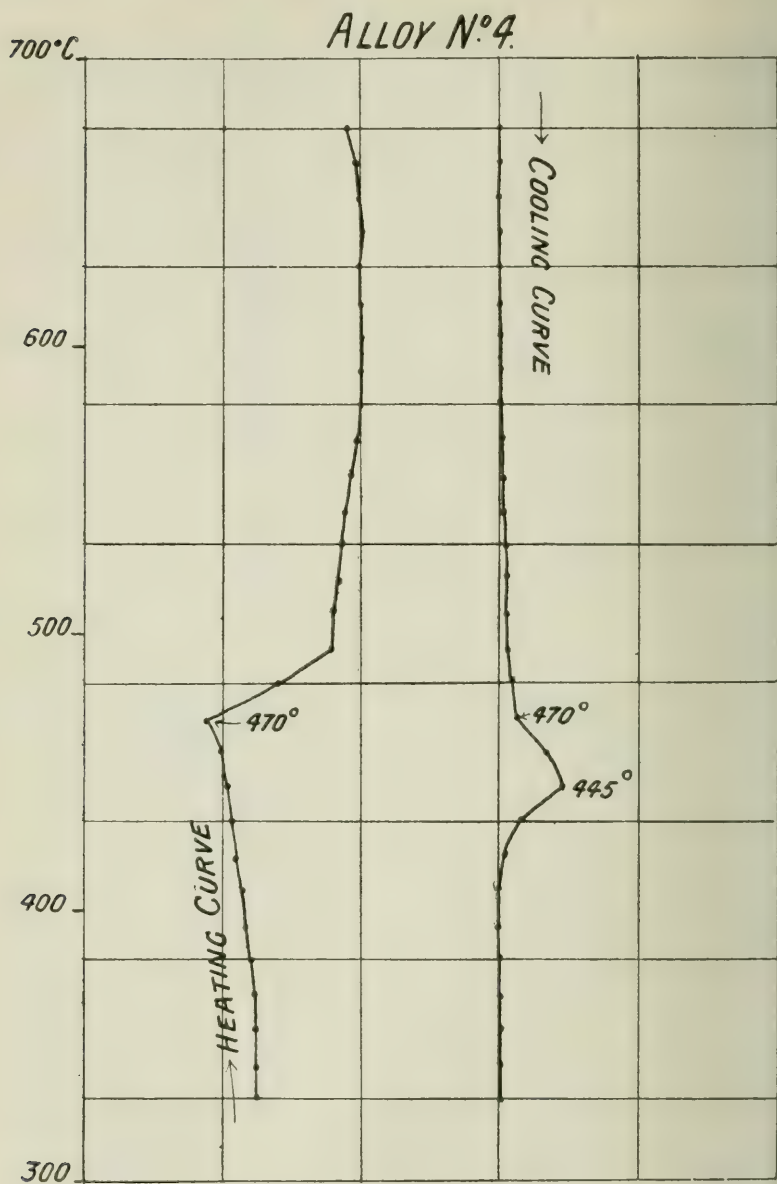
FIG. 6.—Curves of the $\beta + \gamma$ constituents.

respectively—*i.e.* since it occurs in the absence both of α and γ—it is clear that it is due to a change in the β constituent. Therefore, whatever the physical interpretation of this point may be, it necessitates an alteration in Shepherd's constitutional diagram.

If the two curves b_1b_4 and c_1c_2 (Fig. 2) do not actually meet at 470°, then the physical meaning of the critical point would be that there is an allotropic change in β at this temperature, and it would be necessary to modify Shepherd's diagram in the manner shown in Fig. 7. Above 470° there would be the normal β constituent, and below that temperature a polymorphic form of the same constituent described as β'. It should, however, be noted that, according to Fig. 2, β is a homogeneous solid solution which may vary in composition at 470° from 53·5 to 51·0 per cent. copper; in which case the temperature of the critical point ought to be influenced by the composition of the alloy, for the following reason :—Alloys to the left of the point x (Fig. 7) on cooling from temperatures above the line b_1x deposit α at temperatures on that line. The separation of α proceeds with falling temperature, and β is consequently impoverished in copper until at 470° its composition is represented by the point x. Alloys to the right of the point y when cooled from above the line c_1y deposit γ, which means that β becomes relatively richer in copper until at 470° its composition corresponds to the point y. Therefore in these two classes of alloys, if the two lines b_1x and c_1y do not meet, the compositions of β at 470° would be quite different; and if the critical point at 470° were due to an allotropic change, the temperature at which it occurred should be different in the two classes.

But as the critical point indicated on the curves occurs at exactly the same temperature in both series of alloys, this seemed a sufficient reason for discrediting the foregoing hypothesis, and seeking evidence in support of what appeared to be the only alternative explanation.

The second hypothesis is that the solubility lines b_1b_4 and c_1c_2 (Fig. 2) actually meet at 470°, and that at this temperature the following inversion occurs—

$$\beta \longrightarrow \alpha + \gamma.$$
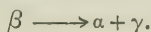
This would necessitate the equilibrium diagram shown in Fig. 8.

Judging from the time and care that Shepherd devoted to annealing alloys consisting of pure β, he was no doubt look-
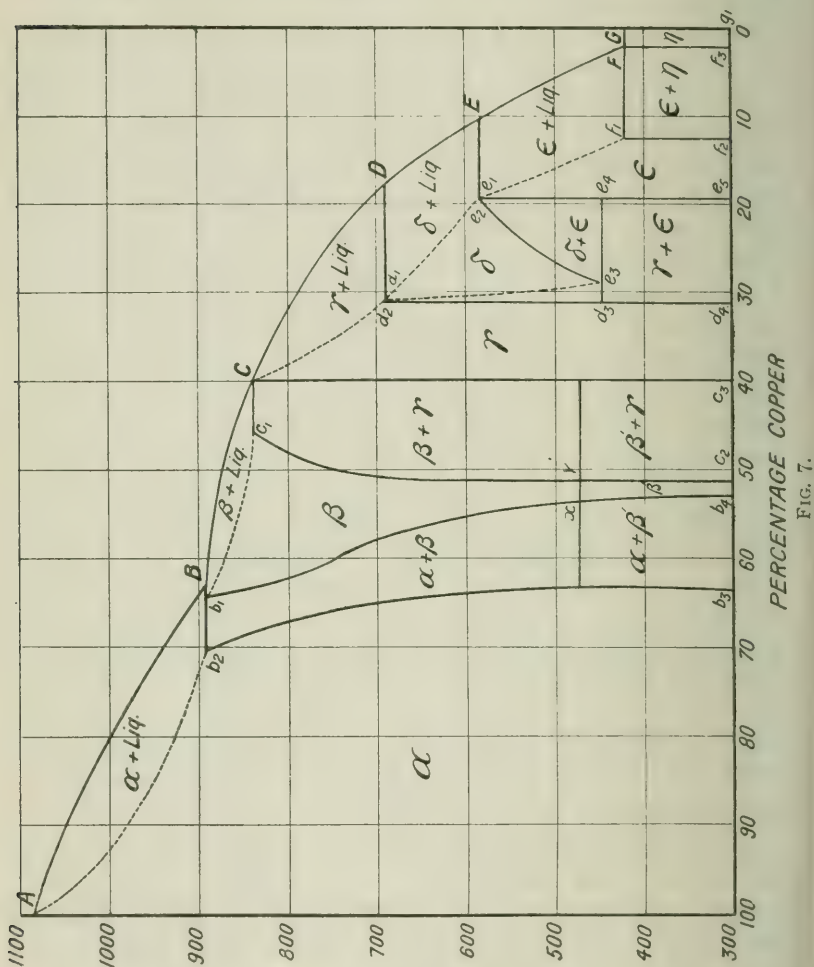
Fig. 7.

ing for a change of this character. He says (p. 424): "The curves b_1b_4 and c_1c_2 do not meet (at least not at ordinary temperatures), for if they did there would be a quadruple point for a, β, γ, and vapour. The β phase would then

disappear on annealing below this temperature with the formation of α and γ. Numerous experiments have shown, however, that α and γ are never present in the same ingot. Between 51 and 53 per cent. of copper the annealed ingots
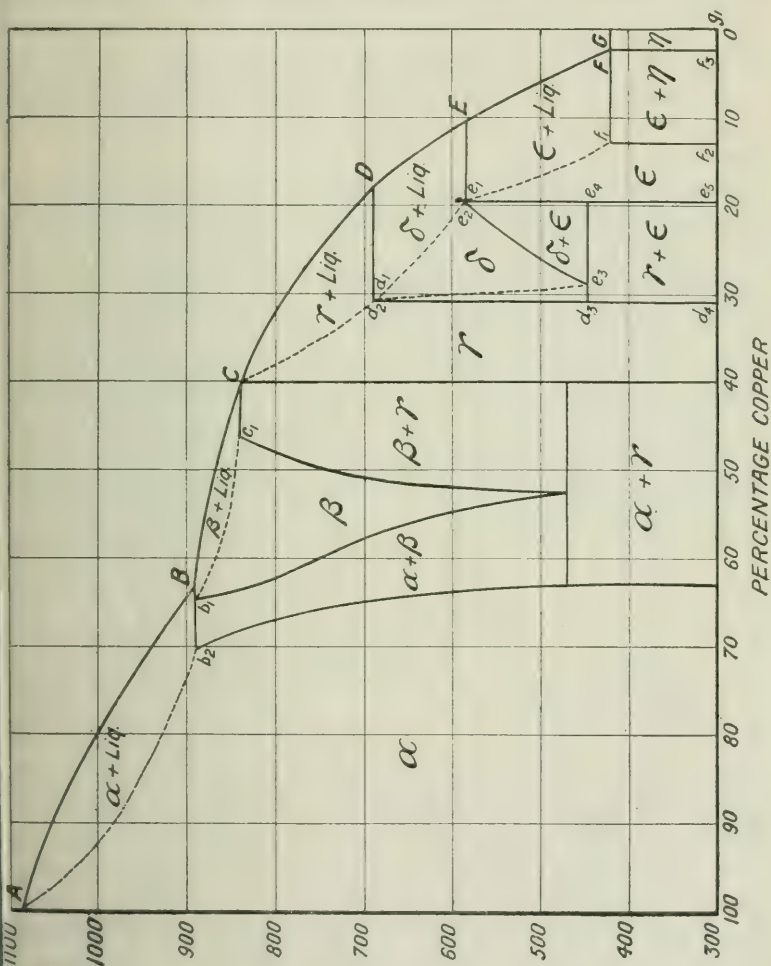
FIG. 8.

consist entirely of the red β crystals. At 54 per cent. copper the ingots consist of mixed red and yellow β and α crystals, and below 51 per cent. copper they consist of red and white β and γ crystals. . . . The 58·5 per cent. alloy is homo-

geneous when annealed at 720° and quenched. It becomes inhomogeneous, showing both α and β crystals, if annealed at 685° and quenched. . . . The 50 per cent. alloy is inhomogeneous, showing γ and β crystals when annealed at 640°, but is homogeneous when quenched from 750°. The 52 per cent. copper alloy differs from all of these by being homogeneous at all temperatures above 400°, and probably at lower temperatures. At least it has not been observed to break down during six months at ordinary temperatures or three days at 300° C."

From these statements it is evident that the change of constitution required by the interpretation given in Fig. 8 must be difficult to detect structurally by means of the microscope.

At this stage it may be well to consider what the effect on the properties of any alloy in this range would be if β decomposed at 470° into α + γ. It is well known that γ is a white and very brittle constituent, and the presence of even small quantities would be sufficient to impart brittleness to the alloy. While the thermal change is quite marked, and the change of constitution must occur with ordinary rates of cooling, it was nevertheless thought that the effects of this change on the mechanical properties and structure, so far as the latter can be resolved by the microscope, might be very slow. Accordingly the authors endeavoured to obtain some old samples of brass, and were fortunate in finding a number of carefully labelled specimens. These specimens, dating between 1850 and 1855, were originally the property of the late D. Forbes.* Among them were a number of small brass ingots and a quantity of brass wire. The wire was labelled : " Brass wire has become extraordinarily brittle after keeping for a few years in the loft." Its date was 1854. It is, of course, impossible to say whether this wire is even more brittle now than it was fifty-six years ago, but it is so brittle that a piece 2 inches long snaps after it has been bent through

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* D. Forbes, F.R.S. (1828–1876), was a geologist, chemist, and mining engineer. His valuable mineral and metallurgical collection was bought by the authorities of the Manchester Museum. For six years he was foreign secretary to the Iron and Steel Institute.

an angle of about 15°. Two such broken specimens are photographed in Fig. 9 (marked A). An analysis of this wire showed that it contained—copper, 63·92 per cent.; zinc, 36·08 per cent.

This composition corresponds almost exactly to the saturated α solid solution. From the fact that this wire contains no β, it might at first sight appear that the brittleness developed is in no way related to the critical point in β at
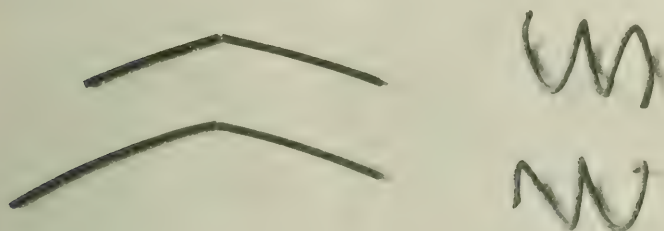
FIG. 9.

↑
A
Brass wire, at least fifty-four years old, which became brittle in a few years' time. The photograph shows fractured specimens broken at an angle of about 15°.

↑
B
Similar wire bent after annealing a short time at 650° to 700° C., showing the entire removal of the brittleness by heating it above the critical point at 470° C.

470° C., especially as a cooling curve of any alloy containing more than 63·5 per cent. of copper—*i.e.* consisting only of α—shows no such critical point. If, however, the conception of the "Nature of Solid Solutions," as enunciated by one of the authors in the Appendix to this paper, is accepted, the connection is quite obvious. This conception, applied to metallic alloys, is: "A solid solution is a homogeneous mixture of the crystals of two metals or intermetallic compounds, and, while these crystals are so small that they cannot be distinguished under the microscope, they are sufficiently large

to retain their identity." According to this view, a is a homogeneous mixture of the crystals of copper and β.

It has already been suggested that the critical point at 470° C. corresponds to an inversion of β into $a + \gamma$. If this can be shown to be the case, then the inference is that the brittleness developed in the brass wire is due to this change
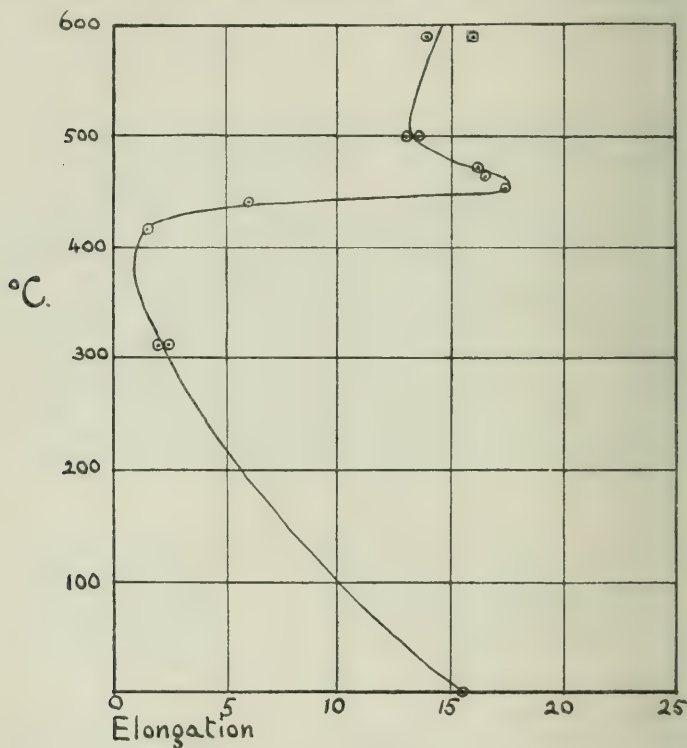
Fig. 10.—Tests at High Temperatures.

(*Reproduced from Messrs. Bengough and Hudson's Paper, Vol. IV.* p. 104.)

slowly taking place in the small β crystals present in the a mixed crystals or solid solution. Therefore it might be logically expected that if this old brittle wire is heated to above 470° C. for even a very short time, the ageing effect of over half a century should be removed, and the wire become, so to speak, as young as when first manufactured. Indeed
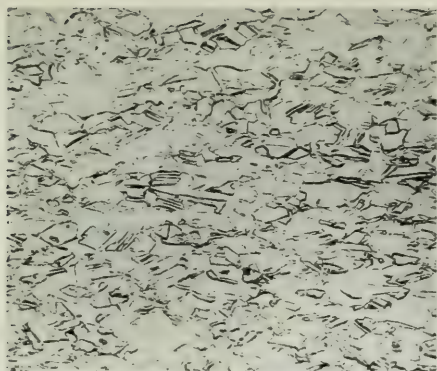
FIG. 1.—Bar HB as rolled.
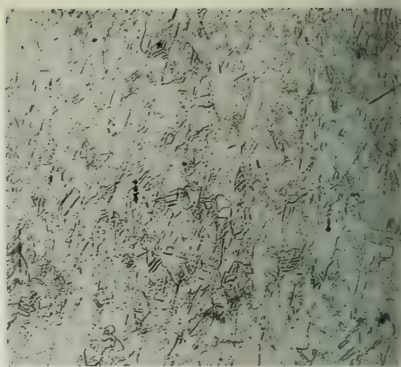
FIG. 2.—Bar HB14. Half-hour at 320° C.
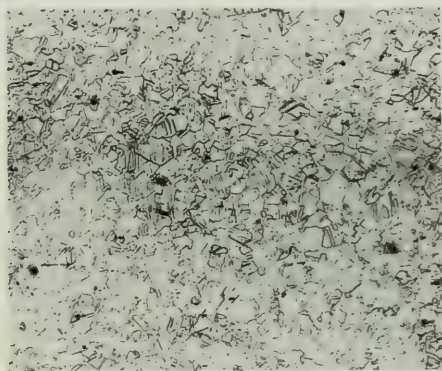
FIG. 3.—Bar HB10. Half-hour at 405° C.
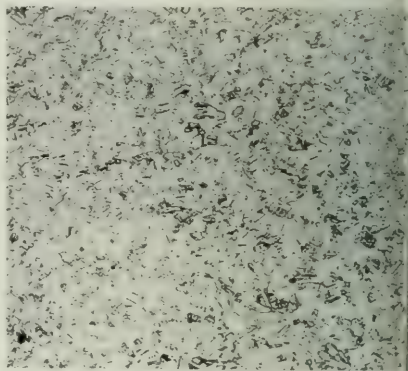
FIG. 4. HB1. Half-hour at 500° C.
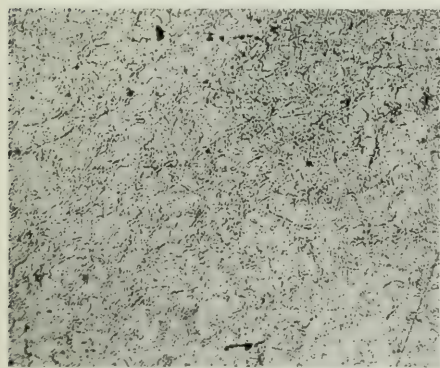
FIG. 5.—Bar HB2. Half-hour at 570° C.
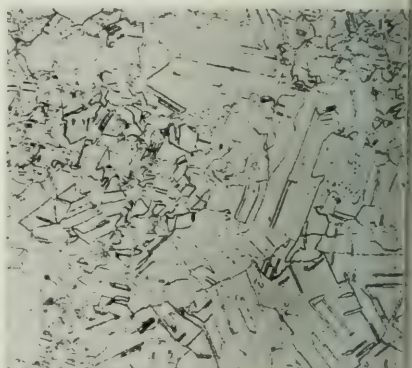
FIG. 6 —Bar HB3. Half-hour at 630° C.

Magnification—100 diameters (reduced 20 per cent. in reproduction). Illumination—Vertical.

(*Reproduced from Messrs. Bengough and Hudson's Paper, Vol. IV.*)

this treatment should be a perfect metallurgical elixir. This was actually found to be the case, for, after heating pieces of the wire to about 650° to 700° for less than five minutes, followed either by a quick or slow cooling, they could be bent and twisted in any direction without showing any signs of cracking. These results are shown in Fig. 9 (B), and they are exactly in accordance with predictions.

A remarkable because quite unconscious proof of the reality of a critical point in the α brasses containing apparently no β, was furnished by Messrs. Bengough and Hudson at the last meeting of the Institute of Metals ([7]). In their experiments on the 70 : 30 brass, *i.e.* on a brass containing only α, the mechanical tests on wires carried out between 300° and 600° C. furnish most striking evidence as to the existence of this critical point. Further, their photomicrographs of the heat-treated alloy are only intelligible on the same assumption.

Evidence from the Mechanical Tests.

In Fig. 10, the curve showing the variation in the ductility of 70 : 30 brass wire between 310° and 590° C. is reproduced from their paper. It will be noticed that the elongation, which at ordinary temperatures is about 16 per cent., fell off rapidly with rise of temperature. At 310° C. it had dropped to 2·5 per cent., and at 415° to 1·5 per cent. Above this temperature, however, there was a sudden recovery, and at 453° it had risen to 17·5 per cent. The authors say " a new maximum value is obtained at a temperature between 450° and 475° C."

What better proof could there be of the existence of some critical change at this temperature, which agrees exactly with that found by ourselves ?

Evidence from the Structures.

Plate I. is reproduced from their paper. A study of this shows that the structure of a bar annealed for half-an-hour at 320° C. is very different from that of the rolled bar.

Still more is this the case for the bar annealed at 405° C. Not only has the crystalline structure seen in Fig. 1 entirely disappeared, but the surface is covered with minute pits. This change is far more fundamental than a mere recrystallisation of a rolled alloy. It is, however, quite intelligible, and indeed just what might be anticipated from the existence of the critical point at 470° C., for just below this temperature the rate of change of β into $\alpha + \gamma$ will be a maximum. Therefore a full development of $\alpha + \gamma$ in Fig. 3 is to be expected, and it is this which causes the minute pitting when the surface is etched.

But at 500° C. the reverse action. viz. $\alpha + \gamma \rightarrow \beta$, has occurred, and. as seen in Fig. 4. the pits have entirely disappeared. This is the region of mixed crystals of β with copper, which appear a homogeneous solid solution. Annealing above this temperature merely causes these crystals to grow (*cf.* Figs. 5 and 6, and also 7, 8, 9, and 10 in the original paper). Thus the structural evidence furnished in Messrs. Bengough and Hudson's paper is in most satisfactory agreement with the theoretical consequences of the critical change at 470° C.

Reverting now to the evidence furnished by cooling curves, Fig. 3 indicates that copper-zinc alloys containing only α do not show the critical point at 470° C. when tested in this way. This leads us to a consideration of the discrepancy that apparently exists between Roberts-Austen's results and our own, not as to the temperature of the critical point, but as to the range of composition over which it can be detected pyrometrically. These ranges are approximately as follows:—Roberts-Austen's observations 75 to 46 per cent. of copper; the authors', 63 to 40 per cent. of copper. As shown in Table I. (page 129), Roberts-Austen examined seven alloys containing only α, between 76 and 63 per cent. copper. Of these only two gave indications of a thermal retardation in the neighbourhood of 450° to 470° C., and these were very slight. *With the remaining five the results were entirely negative.* On the other hand, eight of the ten alloys, containing between 63 and 46 per cent. of copper examined by him, all of which contained β, showed the critical point, and the longest arrests were obtained with two alloys containing 52·1 and 48·1 per cent. of

copper, the former of which corresponds almost exactly to pure β at 470° C. Accordingly the discrepancy noted is more apparent than real. Still the fact does remain that Roberts-Austen's observations appear to show that the critical change at about 470°, which undoubtedly does occur in the α alloys, can also be detected on cooling curves. In other words, whereas our observations point to the conclusion that the inversion can only be detected pyrometrically in alloys containing structurally free β, Roberts-Austen's give some support to the view that it is possible to detect it in alloys containing what may be called "dissolved" β.

4. Microscopical Evidence of the Inversion
$$\beta \longrightarrow \alpha + \gamma.$$
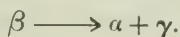
It still, however, remained to be shown by microscopic investigation that below 470° the so-called β constituent in reality consisted of two constituents, and that it therefore possessed a duplex structure. If this could be established it would, of course, be in conflict with all previous work on the subject—*e.g.* Shepherd says ([2]), p. 428 : " The $52 \cdot 2$ per cent. copper alloy . . . is pure β, and does not break down to a mixture of crystals even at 300° C., though annealed for two days at that temperature." It is noteworthy that the magnification of his photomicrograph of this alloy is only 80 diameters. It was considered that the most hopeful line of investigation would be to experiment with alloys containing a considerable amount of β and of varying ages. The authors' anticipation was that Forbes' specimens (already referred to) of more than fifty years from their date of manufacture should, if any, present the duplex structure required by theory, and that specimens of more recent date might show transitional stages between this and the apparently homogeneous structure of freshly cast alloys. Fortunately one of Forbes' specimens gave on analysis a composition corresponding to pure β, viz. $53 \cdot 52$ per cent. of copper, and with this the greater part of the authors' experiments have been made. In response to their request, Sir Gerard Muntz, Bart., kindly furnished them with Muntz metal alloys of ages varying from thirty years to the present

K

day. These alloys all contained $\alpha + \beta$, and unfortunately investigation quickly showed that, on account of the presence of α, they were much less suitable for investigation than the pure β alloys. The reason is, that in alloys containing $\alpha + \beta$, owing to the difference of potential between them when placed in the etching reagent, *they each etch as a whole.* Accordingly all attempts to resolve the structure of β in presence of α have given negative results. With pure β, however, the case is different. If it really consists of $\alpha + \gamma$ this should be developed by etching and be visible under the microscope. After considerable investigation of Forbes' "aged" specimen of β, the authors felt no doubt that in reality it consisted of two constituents. But in order to obtain evidence that might be expected to carry conviction to the readers of a paper who see only photomicrographs, the alloy was subjected to a prolonged annealing at from $350°$ to $400°$ C., in a small electrically-heated muffle furnace fitted with an adjustable resistance. This temperature, it will be noted, was about $50°$ to $70°$ C. below the critical point. From time to time the structure was examined, and after three weeks of annealing it was photographed. The results are given in photomicrographs Nos. 1 and 2 of Plate II. The duplex structure of the alloy is manifest at a magnification of 1000 diameters, but it is seen more clearly at 2500 diameters. Subsequent investigation showed that this duplex structure is manifest in the pure so-called β constituent, freshly prepared and cooled at ordinary rates. This is exactly what the authors' diagram (Fig. 8), based on cooling and heating curves, demands, and there can now be no doubt that below $470°$ C. β does not exist as a stable phase, but consists of a mixture of $\alpha + \gamma$ crystals. This mixture, however, is only resolvable at very high magnifications. Previous investigators appear to have used only low magnifications. Thus Shepherd considered 80 diameters sufficient to decide this point. This is quite inadequate. The duplex structure is not really visible below 1000 diameters.

It still remained to be shown, however, that above $470°$ C. β is homogeneous. Accordingly a specimen was quenched at about $600°$ C., and then photographed. The result is shown

PLATE II
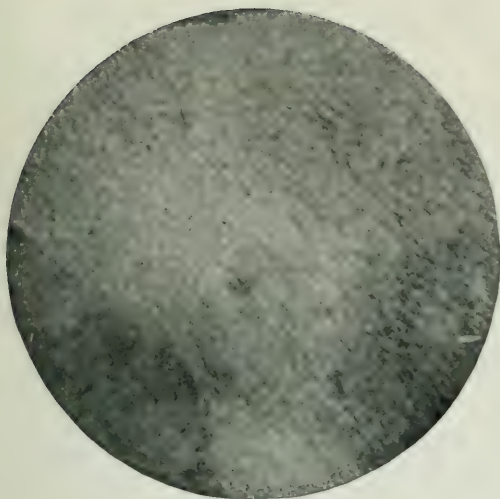
No. 1.—Magnification 1000 diameters.
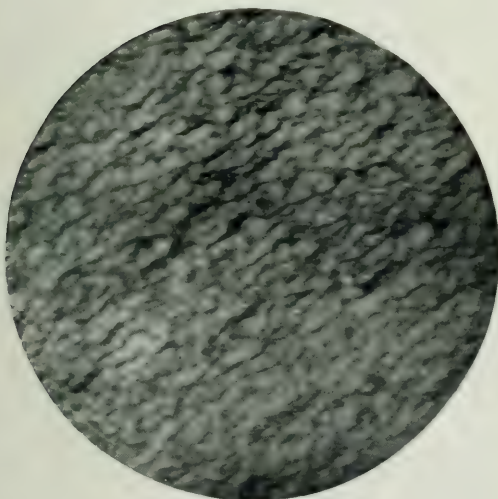
No. 2.—Magnification 2500 diameters.

Showing the inversion of $\beta \rightarrow a + \gamma$ in a specimen of originally pure β after three weeks' annealing at 350°–400° C.
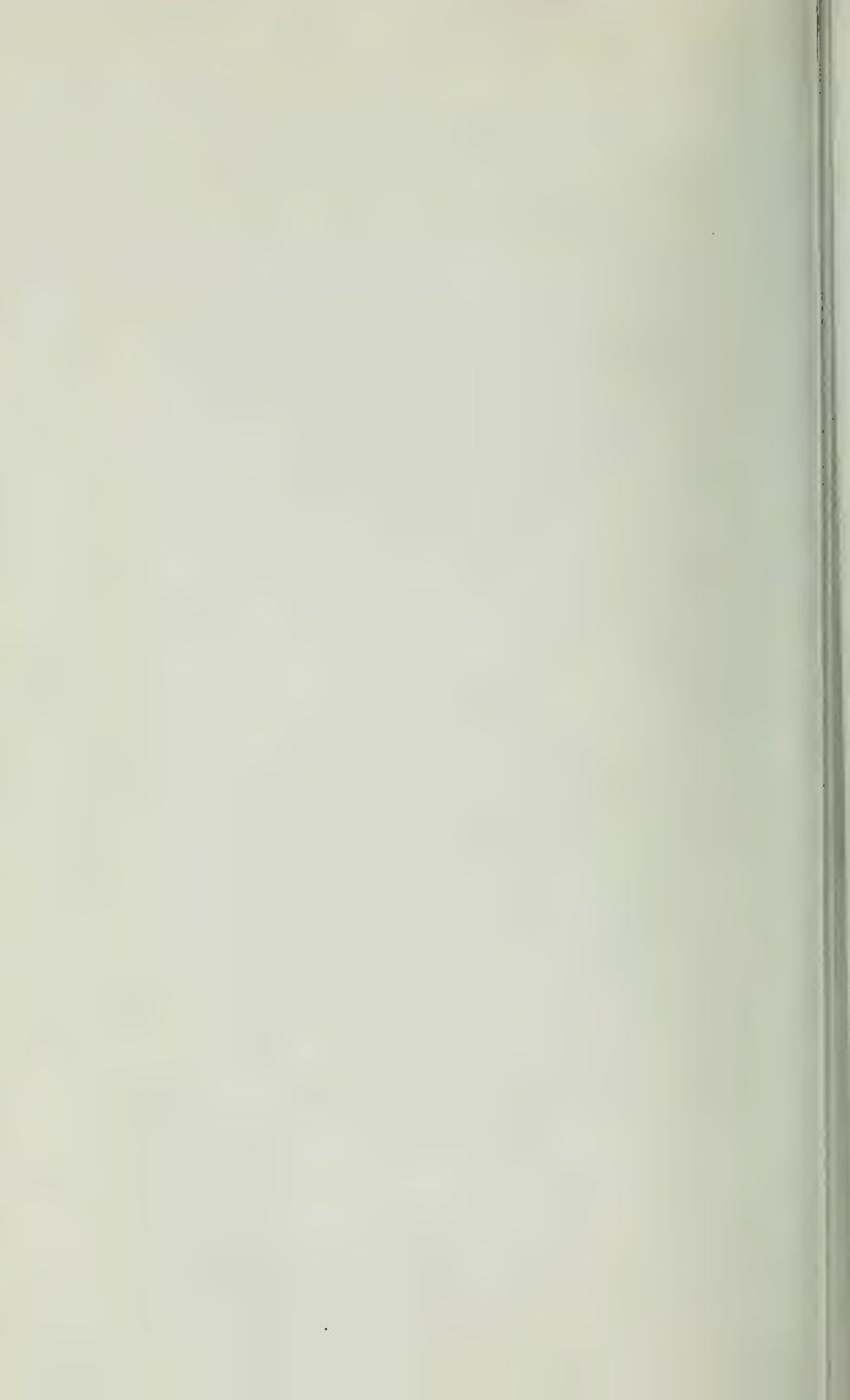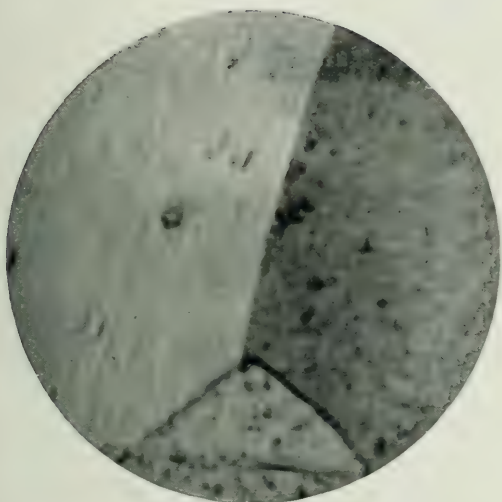
PLATE III

No. 3.—Magnification 2500 diameters.

Showing the homogeneity of β above 470° C.

in photomicrograph No. 3, Plate III. (2500 diameters). On comparing this with No. 2, Plate II., its homogeneity is clear.

5. PRACTICAL CONSEQUENCES OF THE CRITICAL POINT.

The establishment of the existence of a critical point at $470°$ C. in all copper-zinc alloys containing from 60 per cent. of zinc, down to probably a small percentage of this metal, though the lower limit has not been fixed by the authors' investigations, is of great practical importance. It certainly exists in all the industrial alloys of copper and zinc, viz. the brasses, which contain, as a rule, between 28 and 40 per cent. of zinc, in particular in the $70 : 30$ mixture used for condenser tubes, and in the $60 : 40$ mixture used for sheathing. *The net result is an embrittling of the material* owing to the instability of the β below $470°$ C., and its inversion into a mixture of $\alpha + \gamma$, the latter of which is very brittle. The effect on the ductility of condenser-tube metal has already been dealt with (p. 143), but it may not be out of place here to say that it entirely explains the complete loss of ductility at about $400°$ C. found by Messrs. Bengough and Hudson (*loc. cit.*), a loss which was previously quite unintelligible. There are other instances of the deterioration of brasses, hitherto mysterious, upon which the new critical point throws considerable light.

In view of the recent establishment by the Council of the Institute of Metals of a special committee to deal with the causes and prevention of the corrosion of condenser tubes, it is a happy coincidence that the new critical point has an important bearing on this very problem. Hitherto it would have been assumed that these tubes consisted of one constituent only, viz. α, and the investigation from this standpoint would have appeared much simpler than it really is, for if the experiments and conclusions of the authors are correct it appears—

    1. That α consists of a very intimate mixture of copper and β.

    2. That β tends to pass, even in solid solution, into α and γ.

In reality, therefore, the case is complex. Condenser tubes must consist of at least two constituents, copper $+ \gamma$, the latter of which is rich in zinc, whereas the former contains none : γ is accordingly electro-positive to copper. Under working conditions, therefore, with steam on one side of the tube and salt water on the other, is it surprising that corrosion set in ?

The so-called "crystallisation" of brass with consequent brittleness, for which hitherto no explanation was forthcoming, appears as a natural consequence of the new critical point. So also does the failure of brass locomotive fire-box stays in former days.

The important practical problem arising out of the above discovery is as follows :—" Is it possible to suppress the critical point at $470°$ C. by the introduction of some element or elements into the copper-zinc alloys, and thus to avoid the formation of γ and its consequent brittleness ? " If this difficulty can be overcome, the consequences will be far-reaching. It is the authors' intention to take up this investigation without delay.

6. Summary.

1. The thermal change at about $470°$ C. found by Roberts-Austen in certain copper-zinc alloys is a real critical point, and is not due, as Shepherd, Tafel, and Bornemann have asserted, to experimental defects of his apparatus. It is, however, not due, as Roberts-Austen supposed, to the presence of a eutectic.

2. The authors have detected it pyrometrically both on heating and cooling curves, in all alloys containing the so-called "β" constituent as a separate structural entity, *i.e.* from about 63 to 40 per cent. of copper.

3. The interpretation of the change is that at $470°$ C. on cooling, β splits up into an intimate mixture of $\alpha + \gamma$; on heating, the reverse change takes place. Thus above $470°$ C. the stable phase is β, below it is $\alpha + \gamma$.

4. The resolution of β into $\alpha + \gamma$ on cooling below $470°$ C. has been detected microscopically in alloys containing pure β just above $470°$ C. It is, however, only visible at very high magnifications (*cf.* Nos. 1 and 2. Plate II.). The homogeneity of β above $470°$ C. has been shown (*cf.* No. 3, Plate III.).

5. The practical consequence of the critical point is the embrittling of the alloy, owing to the brittle properties of γ.

6. Alloys containing only the α constituent are to be regarded as apparently homogeneous mixtures of very minute crystals of copper $+ \beta$.

7. This conception provides an explanation of the brittleness and so-called "crystallisation" of alloys containing apparently only α, that appear with lapse of time at ordinary temperatures, and much more rapidly between 300° and 400° C. *Cf.* Bengough and Hudson ([7]).

8. The brittleness can be entirely removed by heating for a short time above 500° C. and cooling at ordinary rates.

9. The new critical point involves an alteration of the generally accepted copper-zinc equilibrium diagram. This alteration is shown in Fig. 8, which is now to be regarded as the nearest approximation to the facts.

10. The critical point throws considerable light on the cause of the various types of corrosion, and decay of brasses which have been hitherto unexplained—*e.g.* the corrosion of the condenser tubes of marine engines in service.

In conclusion, the authors acknowledge with pleasure the assistance of two undergraduate students, Messrs. V. Edge and W. Whiteley, in the experimental part of the foregoing investigation.

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6. W. Rosenhain, "Observations on Recalescence Curves," *Proceedings of the Physical Society of London*, vol. xxi., 1908.

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APPENDIX.

THE NATURE OF SOLID SOLUTIONS.

By C. A. EDWARDS, M.Sc.

Whilst the terms " solid solution " and " Mischcrystall " (mixed-crystals) are literally quite different, they are nevertheless used by metallographists for describing the same constituent of metallic alloys. The former was introduced by Van't Hoff, and the latter by Roozeboom. They refer to a constituent formed by mixing two metals which solidify as homogeneous crystals, whose composition may be varied within certain limits. Such solid solutions are regarded as being perfect solutions, and directly analogous to ordinary solutions of salts in water. Simple as this definition may seem, it conveys no precise idea of the manner in which the metals are associated. Indeed, the terms solid solutions or mixed crystals are often very loosely applied.

Solutions.

A solution is defined as a homogeneous mixture, the composition of which can undergo continuous variation within certain limits. These mixtures are frequently stated to allow of no separation of their components by mechanical means. Whether this inseparable condition is indeed a fact is perhaps a matter of opinion.

When a layer of water is brought over any aqueous solution, say of sugar, the system does not remain in this condition. The sugar at once begins to rise against gravity and to diffuse into the water, the motion only ceasing when the substance is uniformly distributed throughout the whole mass of water. This motion may be arrested by placing between the two liquids a septum which will let the water pass through but not the dissolved substance. Such a " semi-permeable " wall can be prepared by filling the pores of a porous earthenware cell with ferric oxide. If a sugar solution is filtered through a

medium of this character, a much greater pressure is required, and what passes through is not sugar solution but pure water. This is certainly not a direct chemical means of separation and can scarcely be regarded as a catalytic action: it must therefore be considered as a mechanical separation. This process of separation is applicable both to electrolytes and non-electrolytes, or, in other words, it is the same for substances that are decomposed into their ions when in solution and those that are not.

It would therefore appear that solutions even of salts in water are intimate mechanical mixtures, capable of being separated to some extent by mechanical means. If this conclusion is correct, then it follows that the identity of salts, which when in solution are not decomposed by electrical currents, is still retained, and even the salts of electrolytes are not completely dissociated when in solution, *i.e.* although these salts are in the ionic state, the positive and negative ions are in some way attached. The mechanism of the passage of the liquid through membranes, as described above, is probably dependent on the relative sizes of the molecules in the solution and the pores of the membrane, and the action of the membrane is that of an exceedingly fine sieve.

Reasoning in this way, it would therefore seem that the molecules of the solute are held in solution by mechanical means, and they should to some extent retain their individual properties.

Metallic solutions appear to offer rather better opportunities for testing this question than aqueous solutions. Before going any further, however, it will be well to define exactly what body is in solution in the case of metallic mixtures.

In a simple series of alloys such as indicated by the diagram in Fig. 11, it is clear that the point a represents the saturation limit of the metal B in A, and the point b, that of A in B. But in such a series as is shown in Fig. 12, it is perhaps not quite so obvious. Here the point a cannot, strictly speaking, be considered as a solution of B in A. Systems of this character really consist of two binary series, viz. of the metal A with the compound AxBy, and of the compound AxBy with the metal B; and the points a and b correspond respectively to solid solu-

tions of A$_x$B$_y$ in the metal A, and A$_{x'}$B$_y$ in the metal B. It is important not to regard this definition as devoid of any real meaning, for if carefully followed up, it may have a far-reaching practical significance. For example, if a compound which shows a thermal change and a definite break in mechanical properties, say at a red heat, is held in solid solution with another metal, and if the identity of that compound is not thereby destroyed, then there may be no corresponding thermal
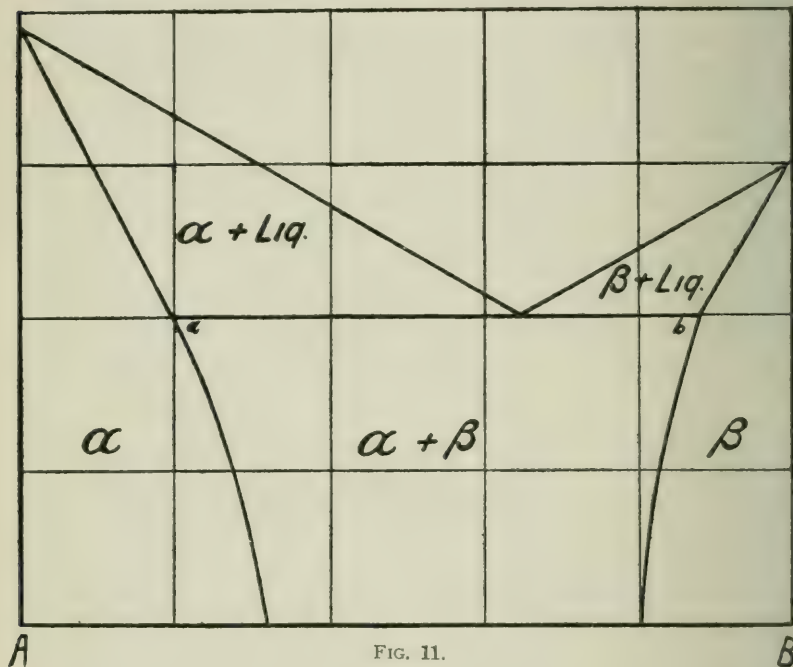
Fig. 11.

disturbance in the solid solution, but it is almost certain that there will be similar discontinuities in mechanical properties, though they might not be so marked as in the pure compound. Perhaps this idea will be more easily understood by considering a typical example.

As previously mentioned, a critical point at 470° C. has recently been discovered in those brasses containing the β constituent. Now while an alloy containing none of the β constituent, *i.e.* consisting of the α solid solution only, shows

no indication of the critical temperature on the cooling curve, it should, if the above conception of the nature of solid solutions is correct, show a break in mechanical properties at about 470° C., owing to the incipient change of the β constituent present in solution. This break has already been discovered by Messrs. Bengough and Hudson by some very careful experiments conducted on the 70 : 30 brass, at temperatures ranging from 0° to 600° C. Their diagram, by which
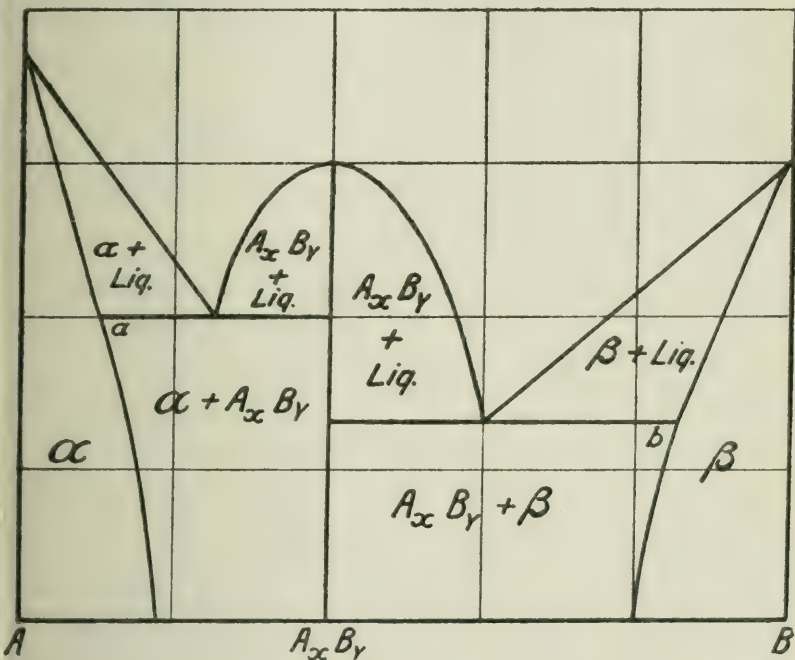
FIG. 12.

they represent the ductility of brass wire at various temperatures, is shown in Fig. 10 (*cf.* vol. iv. No. 2, 1910, p. 104). Here it will be seen that the ductility falls almost to zero as the temperature rises to 410° C., and then rapidly increases and reaches a maximum at about 470° C., a temperature which exactly corresponds to the critical point on the cooling curve. This definite change of ductility is in the authors' opinion due to the change in the β constituent held in solution. Similar

tests made on the copper-aluminium alloys by Dr. Rosenhain [*]
show that these alloys behave in a similar manner, but the
evidence is not so clear, which may be due to the fact that Dr.
Rosenhain's experiments were made with bars half an inch in
diameter, and under these conditions the time factor would
have a greater influence than when testing wire. It is
important to remember that the β constituent of the copper-
aluminium alloys decomposes at about $560°$ C. into the a and γ
constituents, in a similar manner to the copper-zinc alloys.
These facts throw considerable light upon the nature of solid
solutions, and support the theoretical deductions already in-
ferred, viz. "That a solid solution, so-called, of two metals or
intermetallic compounds is an intimate crystalline mixture,
and whilst the crystals are so small that the mass appears
quite homogeneous, they are, nevertheless, sufficiently large and
independent to retain their identity."

From quite another standpoint the suggestion that the
identity of a constituent is not destroyed when in solution was
made some time ago by Mr. Andrew and the author.[†]

In this connection it is interesting to note that Roozeboom's
term, mixed-crystals, is singularly appropriate, and that the
term solid solution as applied to crystalline masses, such as
metallic alloys, is not, strictly speaking, correct.

Intermetallic Compounds.

There are many contradictory statements in published re-
searches as to whether certain constituents of alloys should be
regarded as compounds or not. Some authors consider that a
constituent should not be described as a compound if it forms
a series of mixed-crystals with either of its constituent metals.
This contention is correct in so far as such conditions render
it difficult or impossible to allocate a definite formula for a
constituent of this character, but it is certain that these con-
stituents must have, as their base, an intermetallic compound.

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[*] Discussion on the Eighth Report to the Alloys Research Committee, *Institution of Mechanical Engineers*, 1907.

[†] "The Constitution and Properties of the Aluminium-Copper-Tin Alloys," *Journal of the Institute of Metals*, No. 2, 1909, vol. ii.

That this is the only logical conclusion will be evident after the following simple facts are taken into consideration.

In a series of alloys which show only two branches on the liquidus curve, and give rise only to two constituents, as in the case of Fig. 1, there is clearly no question of there being any compound present. All alloys consist of either a, $a + \beta$, or β: the a and β may be regarded as a series of mixed-crystals of the metals B with A, and A with B, which contain respectively a preponderating quantity of A and B.

When a pair of metals are isomorphous, they crystallise together in all proportions to form one series of mixed-crystals. There are, however, cases where mixed-crystals are formed only to a limited extent at each end of the series, and others where, in addition to the mixed-crystals at each end of the system, quite distinct mixed-crystals are obtained in the middle of the series. The alloys of copper with aluminium may be taken as a typical example of the latter type. A section of the most recent constitution diagram of this series of alloys, as worked out by Curry,[*] is shown in Fig. 13.

In such cases the writer considers that, apart from the two series of mixed-crystals present at each end of the system, each constituent has a compound as its foundation. It would be quite illogical to suppose that the a and γ constituents in Fig. 4 were respectively mixed-crystals of A in B and B in A, and that the β constituent was also a series of mixed-crystals of pure A and B. It would in fact be tantamount to considering that three distinct consecutive series of mixed-crystals of two metals could be formed without any fresh combination having taken place. Therefore with constituents like β (Fig. 14), there must be a new compound formed, though it might be impossible to determine its formula.

The conclusions to be drawn from this paper are :—

1. That a metallic crystalline mass often described as a solid solution is an intimate crystalline mixture, and whilst the primary crystals are so small that the mass appears quite homogeneous when viewed under the microscope, they are sufficiently large to retain their identity.

2. The term solid solution is not, strictly speaking, applic-
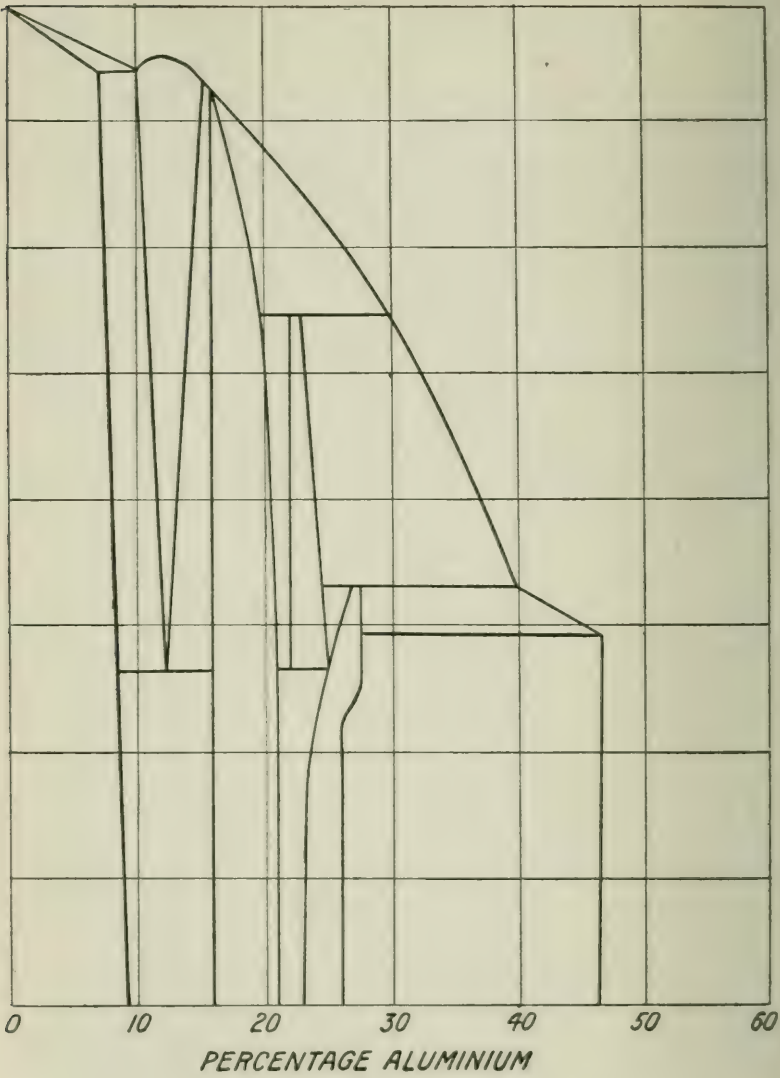
Fig. 13.

able to crystalline bodies such as metallic alloys, and should be restricted to supercooled liquids, such as glass.
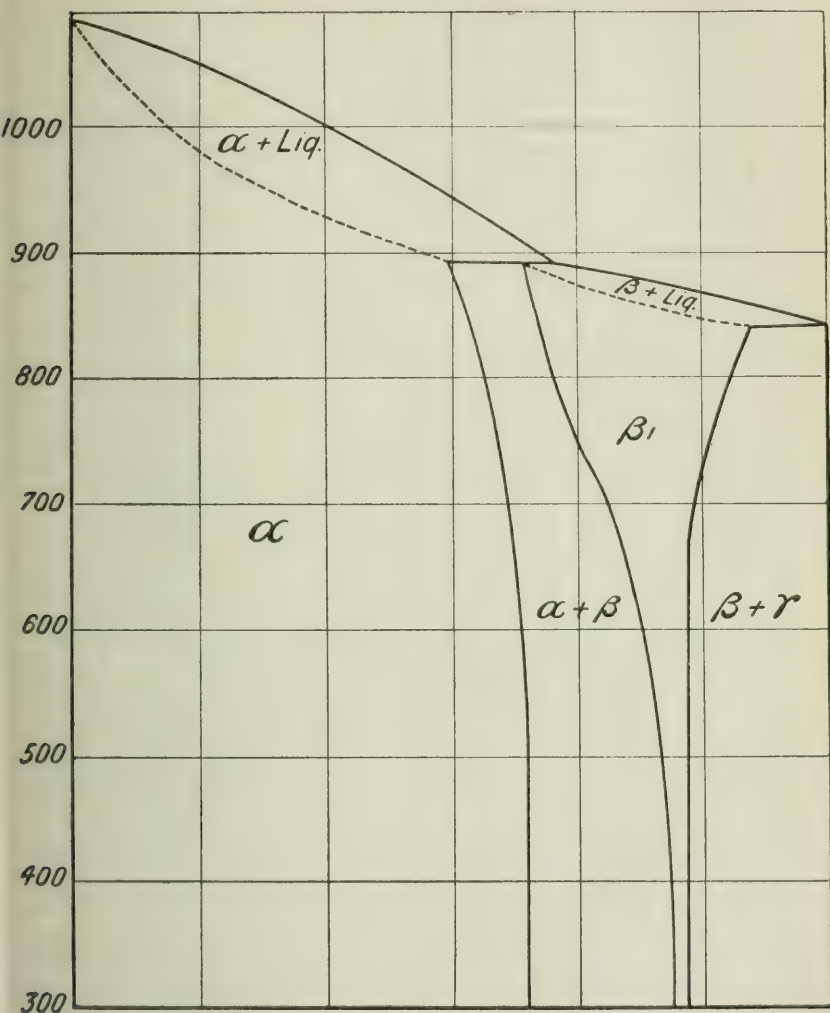
FIG. 14.

3. With the exception of the two series of mixed-crystals that may be formed at each end of a series, each constituent has a compound as its foundation.

DISCUSSION.

Dr. W. ROSENHAIN, Member of Council, said he had read the paper with the greatest possible interest, and from one point of view with the greatest possible pleasure. He shared with Dr. Carpenter the feeling of delight at seeing the original observations of Roberts-Austen vindicated in the manner shown in the paper ; and he thought the discovery, or rediscovery, of the critical point by the authors clearly showed that the diagrams which had been published by some workers required a considerable amount of revision. He was particularly interested in seeing one of Mr. Shepherd's diagrams revised in that way, because during the last twelve or fifteen months his colleague, Mr. Archbutt, and himself had been engaged in revising another diagram, and their revision was much more radical than in the present instance. It was an example of a case where the author had not published his evidence as fully as one would wish, which made it difficult to know just how clearly many of his conclusions were established.

Any one looking at the heating and cooling curves in the paper could not doubt the existence of a very well-marked critical point in the alloys containing the β body of the copper-zinc series ; but when one came to the interpretation of those curves, he was afraid he could not follow the views of the authors at all fully, and he desired to mention why he could not do so. First of all, the authors' *rejection* of the critical point as a transformation or polymorphic change of the body itself, what the authors called an "allotropic change of the β," was based upon the constancy of temperature of the inversion, and apparently the evidence was based upon four heating and cooling curves. Confining their attention to the cooling curves, he noticed that two of them gave temperatures of 457°, the third gave 445°, and the fourth did not indicate the temperature at all : so that there were three temperature measurements, one of which was 12° lower than the other. From what he knew of Dr. Carpenter's method of making experiments, he was quite sure that 12° was not an experimental error. He therefore thought the authors' rejection of the β' on the ground of the constancy of temperature was at any rate not fully established. If there were fifteen or twenty curves, and they all agreed that there was an approximately constant mean temperature, then they would be justified in rejecting it on that ground, but he thought as the evidence stood it was at any rate incomplete. Dealing with the evidence of the duplex structure, it was always exceedingly difficult to judge of a thing of that kind from a photograph. He had not had the paper before him long enough to repeat the experiments, but he had examined a few etched β brasses with a very high power, and had tried to discover signs of the duplex structure, and so far he had failed to do so, although he did not say that he always would fail. But, apart from that, he could not recognise its existence in the photograph on Plate II. ; in fact the lower photograph at the high magnification struck him, on the face of it, and judging it merely by what it was, as being

merely the etched structure of a crystalline solid, such as would be obtained by a moderately deep etching of any crystalline aggregate. He had photographed such structures in very pure iron. The results were negative; at any rate he was not convinced by the photographs, although, needless to say, he was open to conviction if more conclusive evidence were forthcoming. The point made by the authors, that the crystals did not grow, was to his mind an absolute barrier to accepting the whole theory. It would be a unique instance of a case where the decomposition-products of a homogeneous solid did not aggregate into a coarser state of aggregation when exposed to a suitable temperature. Every one who had treated alloys knew it was an absolutely universal fact that such reactions always in the course of time led to a comparatively coarse structure. That was the case in copper-aluminium, copper-tin, and aluminium-zinc, in fact in every case where there was a decomposition of that kind. If one kept on annealing alloys such a duplex structure was obtained, and it would be an extraordinary thing if the copper-zincs in that one particular case proved an exception, while they did not in the other reactions of the system. Finally, the mechanical evidence was unfortunately almost all based on the behaviour of the a body, in which even the revised pyrometric methods used had failed to reveal the thermal evidence of inversion. Where the β body was present the thermal inversion was sufficiently definitely known, but it was necessary to strain the powers of the microscope to the utmost extent to obtain any evidence at all of duplex structure, assuming there was any evidence. On the other hand, in the a, where there was no sign of thermal change at all, mechanical evidence could be obtained of the most convincing kind. He was afraid that he saw no connection between the two. No connection had been established in the paper, and he thought there was very grave reason for doubting whether there could be any. His reason for saying that was that the whole thing was based on a theoretical conception put forward in the appendix to the paper, and that theoretical conception he could not accept for a very serious reason. The view that a solid solution was a homogeneous mixture of the crystals of two metals or intermetallic compounds was to his mind incompatible with the phase rule.

Taking a solid solution whose liquidus was AbC (Fig. 1), and whose solidus was AdC, there was a region $AbCd$ of solid plus liquid. At any point γ there was in equilibrium a solid solution of a definite composition and a liquid. This could never be the case, according to the phase-rule, if the solid were not homogeneous. If it consisted of two definite sets of crystals there were two solid phases, and the liquid phase made three which could only exist at a constant temperature. Therefore he entirely failed to see how that conception could be justified from that point of view. There were any number of other lines of evidence, which he did not wish to go into at the present moment, because the one he had described was, he thought, quite conclusive. He was inclined strongly to deprecate the suggestion that the term "solid solution" should be replaced by what he could not help thinking was a misleading term— "mixed crystals." There was no evidence at all in actual fact that there

were two kinds of crystal present. It was merely a theoretical conception, which one was almost inclined to think had been derived in order to explain that particular set of phenomena, and it was not theoretically as sound as one would like it to be. The whole question of what a solid solution was had been raised in a very interesting form in the paper, and the members were indebted to the authors for the work they had done in that respect. There were certain other conclusions in the paper, with which he was in cordial agreement, which were very clearly set forth. One was that a compound in a solid solution might retain, and frequently did retain, its character as a compound. That did not necessarily mean that it was not in solution : it did mean that it was not in ionic solution in the way that a salt was in solution in water. But there were other
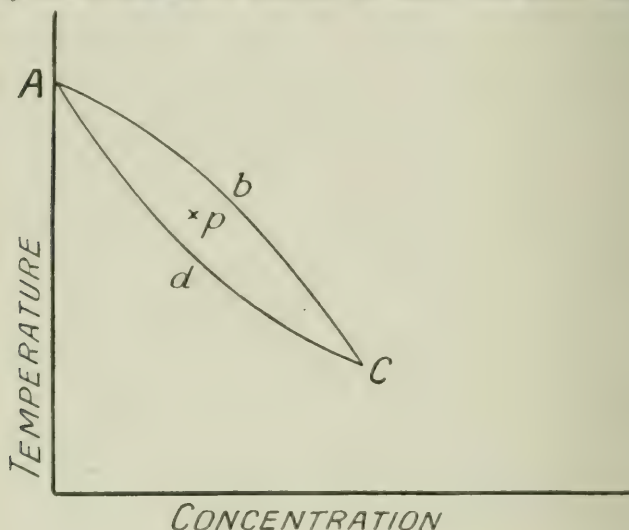
FIG. 1.

solutions in which the compound bodies could go into molecular solution, and he had recently obtained an example of that kind which bore out one of Mr. Edwards' contentions.

The diagram (Fig. 2) represented part of an actual equilibrium diagram. At P was the composition of the compound; it was unstable above the temperature RS, and unstable below the temperature VW. On the side marked δ it formed solid solutions. Along the line RS there was a reaction, $\gamma + \text{liquid} = \beta$. On the left-hand side there was liquid left, which finally solidified as a eutectic, so that there was a region of $\beta + \text{eutectic}$; along VW the β body underwent decomposition, so that $\alpha + \gamma$ was again formed. On the side marked δ the alloys were perfectly homogeneous through the range from RS to VW; but nevertheless below VW the β underwent decomposition, and $\alpha + \gamma$ was again formed. At the same time the phase-rule made it impossible

to consider that there were three constituents present below *VW* in the way that Mr. Edwards' theory would suggest. He had definite evidence to prove that in this case a compound in solid solution had retained its character as a compound. It could undergo that transformation, but it could not exist in the solutions as definite crystals of its own kind. There was a distinction in that respect between molecules and crystals. The
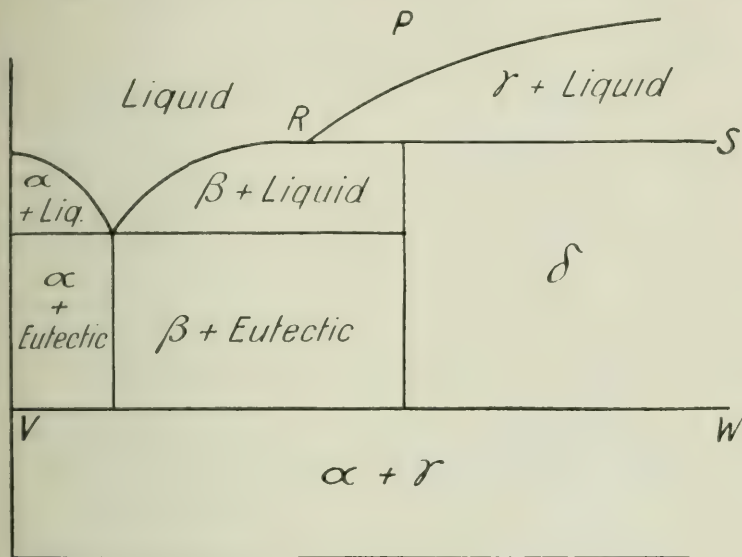
FIG. 2.

molecules of the compound were there as such, but he did not think it was possible to speak of them as crystals. The conception that a body is present in the form of ultra-microscopic crystals implied that molecules, all of the same kind, were grouped together to form minute crystals; his (Dr. Rosenhain's) own view of a solid solution was that the crystals were built up of both kinds of molecules indiscriminately. That was a vitally different view from that put forward by the authors.

Mr. G. D. BENGOUGH, M.A. (Liverpool), said it was hardly necessary to say that he had been very much interested in the paper, and he was confident the same remark would apply to all those present. He differed from the last speaker, and thought the authors could claim to have established their point, and if that was the case the paper marked an epoch in the history of brass. There were several points on which he desired to make a few remarks, the first of which occurred on p. 141, where a statement was given of Mr. Edwards' view of the constitution of what had hitherto been called solid solutions. He was prepared to accept for the present that interpretation of the term "solid solution,"

because he thought it represented the facts with which they were acquainted at present in connection with solid solution better than any other view that had been put forward; and, in referring to the rest of the paper, he would assume that conception to be correct. Before dealing with a few of the theoretical conclusions, he wished to interpolate a remark with regard to the curve that the author had published taken from a paper by Mr. Hudson and himself. Professor Carpenter had remarked that the temperature of their curve at which the second maximum amount of ductility occurred was a temperature of somewhere about 450°, whereas he would expect it, according to his work, to occur at 470°. He thought that discrepancy could be explained in part by the following considerations. Their wires were hung vertically in an electric furnace, and weight was put on a stirrup that was attached to the bottom of the wire. The electric furnace was the ordinary form of resistance furnace. The temperature along the wire would not, of course, be absolutely uniform; it must vary slightly. Mr. Hudson and himself found that it was nearly constant for a distance of 2 inches along the wire. A thermo-couple was wired on to the wire, and in that way they obtained the temperature as accurately as they could, but the fracture did not usually occur actually at the thermo-junction. That might give a small error in the temperature readings as far as their curve was concerned. They did not consider for a moment that the accuracy of their temperature measurements was equal to that of Professor Carpenter's. They did not use the differential method of taking temperatures; they merely used a direct-reading pyrometer, partly on account of the difficulty of the other observations which were being made. He thought that might in part explain the difference between their temperature readings and the authors'. The authors referred very fully to the paper of Mr. Hudson and himself on page 143, the remark being made : " A remarkable because quite unconscious proof of the reality of a critical point in the α brasses containing apparently no β was furnished by Messrs. Bengough and Hudson at the last meeting of the Institute of Metals." That sentence was quite justified by a study of their published paper. Nevertheless, the possibility of a critical point had been raised and discussed by Mr. Hudson and himself during the course of their work, but at the time of publication they decided that they were obliged to reject for the present any idea of the kind. The reason they rejected that idea was the following. They found that both Shepherd and Tafel, working with greater accuracy as regards temperature measurements than Mr. Hudson and himself were, both rejected any idea of a critical point there. They therefore thought that if they were to suggest that a critical point existed they would be in the position of trying to correct results obtained by more accurate methods by means of results carried out by less accurate methods. That, of course, would have been a perfectly unjustifiable proceeding, and they drew the only alternative conclusion under the circumstances, namely, that that interpretation of the point was not tenable. In addition to that, their supposed critical point had at that time only been observed in a brass of one composition, 70 : 30, so that in any case it was doubtful whether they would have been justified in hinting

at its existence. Speaking for himself alone, and no longer associating himself with Mr. Hudson, because he did not know whether that gentleman entirely agreed with him, he was prepared to accept the change as interpreted by the authors as almost certainly the most probable one. With regard to the change taking place in the a brasses, which Dr. Rosenhain in particular seemed to think was doubtful, it was possible that that was helped in some way by the work that was put on the metal. They found that in highly worked brass, where, for instance, it had been drawn, the change was most marked, and this might be attributed to the change being assisted in some way by the work put on the metal. He had particulars of two sets of experiments which seemed to throw light on the work, and which he desired very briefly indeed to lay before the members. The first was the following. He had been working, since the publication of the paper by Mr. Hudson and himself, on the mechanical properties of alloys at high temperatures. Amongst other alloys, he had been examining an alloy of the Delta Metal type, and had determined its mechanical properties at high temperatures, and he had obtained the elongation at a series of temperatures. That elongation underwent an extraordinary change at a temperature of just about 510°, a rather higher temperature than that found by Professor Carpenter for his change. It was a perfectly extraordinary change. At the ordinary temperature the sample of δ metal had an elongation of 25 per cent.; it rose at 300° to 47 per cent.; at 350° to 60 per cent.; at 420° it was practically the same; at 440° it fell slightly to 51 per cent.; at 500° it went down still more to 44 per cent.; at 515° it rose to 68 per cent.; and at 520° there was an elongation of 106 per cent. He had obtained the figure of 106 per cent. within 1 per cent. on four different tests, the figures being 105, 106, 105, 106. That extraordinary increase in elongation was therefore a factor that must be taken carefully into consideration. He did not propose at the present moment to go into the interpretation of that complete curve; all he wished to say was that he thought it was quite reasonably explained by Dr. Carpenter's conception of the change. The members would notice it occurred at a rather higher temperature than that found by Dr. Carpenter and Mr. Edwards. But the alloy he (the speaker) worked with contained aluminium, iron, and manganese in small amounts, and those metals might very likely have the effect of raising the temperature at which the critical point took place. He hoped the complete explanation of that curve might be submitted to the Institute of Metals on some future occasion, and he thought it could be very well fitted in and explained by the conceptions of the authors of the paper. He had also found a critical change in the ductility of brasses of composition other than that 70 : 30 specimen examined by Mr. Hudson and himself. There was another entirely independent line of argument by which he thought they could infer the change of β to $a + \gamma$: at any rate they could show there was some change taking place in the β. Some two years ago he endeavoured to measure the rate of change in Muntz metal, which was really a metastable alloy. If Muntz metal as it ordinarily came from the works was annealed at high temperatures, some of the β changed over in accordance with

Shepherd's diagram into α. He tried to measure the rate at which the change from β to α took place. He took a sample of the metal, heated it up for an hour or two, and then measured the relative proportions of the two constituents. He then heated it for a further period and measured again; and went on increasing the length of time until he could find out when a condition of equilibrium had been reached, *i.e.* when further heating brought about no difference to the proportion of the constituents.

At a temperature of 730° C. he found the relative proportion of the constituents for true equilibrium was something like 84 per cent. β and 16 per cent. α. At a temperature of 630° C. he obtained rather less β and more α; and at a temperature of 530° he found again that there was less β still and more α. He drew a curve from those three results, showing the alteration in the proportions of β with the temperature. By drawing that curve he could, of course, by extrapolation find out at what temperature there should be no β; and the temperature he obtained by that extrapolation was 445°, which was slightly lower than the temperature given by the authors in the paper. That was a very remarkable result, and he was very discouraged with it, thinking that he was at least 440° wrong in his measurements, because he accepted Shepherd's and Tafel's results as more accurate than his own. He accepted the result of those authors in preference to his own, because they were using well-established experimental methods, whereas his own method was a new one. He then came to the conclusion that he must reconsider his method, which he began to think must be valueless; but, as a matter of fact, his result now agreed fairly well with that obtained by Professor Carpenter and Mr. Edwards, because the β partly changed over to γ, and so the area occupied by β never entirely disappeared. If that was followed out to its conclusion, it would be found that that result of his agreed very well indeed with that put forward by the authors. At the end of the investigation he annealed an alloy for two weeks at 440°, just below the point at which the β would disappear altogether according to the measurement he had made. He was so discouraged at the time, and so busy with other matters, that he did not trouble to examine the specimen, which remained in the laboratory untouched. When he received Professor Carpenter's paper, he polished up that specimen and etched it; and, on examining it, he found that the β constituent showed very distinct signs indeed of breaking down. He etched it with ammonia mixed with three parts of water, and got an ordinary lightish-yellow β, as he thought, and bars of a black etching material. That black portion, according to the authors, would be the γ, which was darkened by the ammonia etching, and the lighter material surrounding it would probably be metastable β, the change not being complete, although the specimen was annealed for two weeks at 440°. The only point on which he differed from the authors was, that he saw that change quite clearly at a comparatively low magnification. He photographed it at 500 diameters, and it was clearly visible at only an eyepiece magnification of 250 diameters, which was a very much lower magnification than had been used by the authors. He was sorry to say that his instruments

did not permit him to go up to the high magnification that the authors were able to use, but he was quite prepared to send the specimen to the authors, because it undoubtedly showed a breaking down in the β. There was also one other slight difference from the authors' results. Professor Carpenter said, on p. 146 of the paper, that the β etched as a whole. From that it probably appeared that they were using different etching reagents, which enabled him to resolve the β, which in his experiment did not etch uniformly. Its etched structure was that of black bars across a considerably lighter field, the black being the γ, the intermediate material some metastable β, and the lightest material of all the α. With regard to the authors' reference to corrosion, he thought their conception of the nature of solutions was certainly the best explanation available at present for the dezincification of brass condenser tubes. He thought the conception put forward by Mr. Edwards, that solid solutions had a minutely duplex structure, was just what was wanted to explain the dezincification of brass when corroded by sea-water. With regard to the separate portion of the paper written by Mr. Edwards, he wished to say that, in a paper read by Mr. Hill and himself before the Institute in 1910, they also came to the conclusion that compounds retained their identity in solid solution. Mr. Hill and himself said, in referring to Cu_2As_5, a compound that they considered occurred in the copper-arsenic series : "It follows, therefore, that the inversion at $710°$ C. follows the compound Cu_2As_5 into its solution in both directions. Hence the compound must preserve its identity, at any rate, in part, even in solid solution." An alternative to Mr. Edwards' view was, that "solid solution" should be considered of a colloidal nature.

Professor A. K. HUNTINGTON, Assoc.R.S.M., Vice-President, thought there could be no doubt whatever that Professor Carpenter had discovered the new critical point on the equilibrium diagram which had been mentioned ; the evidence was complete in regard to it as far as one could see. The whole question in dispute was as to the interpretation of what that point meant. Personally, he desired to look at it entirely from a practical point of view, whereas, at the present moment, it was being viewed a good deal from the theoretical point of view. There was no doubt that the critical point had some very intimate connection with the elongation curve depicted in the figure on p. 142, which was taken from Messrs. Bengough and Hudson's paper. But while there was no doubt about that, it was necessary to bear in mind that it only concerned the metal when it was at that temperature. If the temperature was lowered the conditions were at once altered, and that in itself was an important point, because people were very apt, in considering the paper, to confuse what happened at the high temperature with what happened at the normal temperatures, which was a vastly different thing. They were not always using the metal at high temperatures above $400°$ C. If the authors' conclusions meant anything, they meant that all copper-zinc alloys, given sufficient time, would become brittle. If reference were made to Fig. 8, and p. 140, particulars of that statement would be found. When the author was giving a résumé of his paper, he seemed to him (Professor

Huntington) to be rather hedging on that point, because he confined himself to the α metal, and dismissed all question of the $\alpha + \beta$ and β. That would not quite do, because the author had made a very distinct statement in his paper, that all copper-zinc alloys, from 25 per cent. of zinc right away up as far as one could go for all practical purposes, were affected. That was a statement about which many present were not in agreement. First of all, what was sufficient time? For all practical purposes they knew that the alloys gave an elongation of anything they liked from 20 per cent. to 40 per cent. or more under normal conditions in everyday work. Personally, he could not understand where the brittleness came in. There were thousands and thousands of tons of those materials in existence in the world, and for every 1000 tons in use, how many tons, or fractions of a ton, did they hear about as being brittle? Of course, he did not dispute that brittle metal was sometimes obtained, but Professor Carpenter's statement would imply that it was an everyday sort of thing to have the usual metals with which engineers worked in a brittle state. As a matter of fact that was not the case. The paper rather staggered one at first. Looking at it from the authors' point of view, and taking the β metal just at the commencement of the β stage, there would be 70 per cent. of α and 30 per cent. of γ present. That metal would naturally be exceedingly brittle. It was open to the authors to say it would take a great many years before that condition was arrived at: his contention, on the other hand, was practically they never did arrive at such a condition. Professor Carpenter seemed to have been led to that idea by what happened in the case of the tin-copper and aluminium-copper alloys. There an $\alpha + \delta$ eutectoid was obtained, but it was comparatively in quite a coarse crystalline condition. It was segregated, it was perfectly obvious, at a low magnification; but the authors had shown them that there was nothing of the kind in the brasses. In the case of the ordinary zinc alloys, the authors found it necessary to use a magnification of 1000 or more in order to discover the constituents, although there was an absolutely distinct difference between the two. Dr. Rosenhain had referred to the point that Professor Carpenter did not seem to be able to segregate the α and γ, which the authors said were separate. Of course the point remained open, that it might not be done at the temperature at which it had been tried; it was open to say that it required some particular temperature which had not been tried, but what was that temperature? Professor Carpenter had examined some brittle metal which came from Professor Forbes' collection, and that seemed to give one of the few points in his favour—that 36 per cent. of zinc was found in it and no β. He had himself, altogether apart from this paper, recently made up alloys with 36 per cent. and even less of zinc, and that was the transition point between α and β. He found that those alloys, instead of being all α, contained quite an appreciable amount of β constituent, even after annealing. He did not mean to say that if he had gone on annealing for a longer period he would not have got rid of it, but they were annealed for at least one hour, and he thought, in one case, the annealing was repeated without

getting rid of the β. If the alloy referred to by Professor Carpenter was all α, it must either have been annealed for a long time, or else there had been some change going on for fifty-six years, which would be a point in favour of Professor Carpenter to some extent. Mr. Bengough had referred to the change which took place in the β, which he said was quite visible. It would have been much more to the point if Mr. Bengough had stated what sort of a mechanical test that metal gave. He did not know whether the metal was brittle, whether Mr. Bengough tried to fracture it, or whether he obtained particulars of its mechanical properties.

Mr. BENGOUGH stated that the piece of metal was only quite a small specimen.

Professor HUNTINGTON, continuing, said they did not know at present what effect that kind of annealing had on the mechanical properties. In the next place, he wished to refer to one or two points which appeared to him to disprove, or went some way towards disproving, the views held by Professor Carpenter. The fact that it was possible to etch a metal like β metal was due to an electrical effect—at least that was generally considered to be the case, because it was the only explanation of it that could be obtained. The electrical effect was due to the differences in the angles at which the axes of the crystal were cut, and it was due to that difference that any etching at all took place. If the β was transformed into $\alpha + \gamma$ there would not be any such electrical effect at all. The crystals no longer existed; they would be destroyed, and the crystals could not be etched up separately. It would be found, however, in the last illustration in the paper that β crystals were etched in the most marked manner after annealing above $470°$, *i.e.* above the transition point. But on the previous page, in that at 1000 diameters, and not annealed above $470°$, β crystals were quite distinctly shown, which should not be the case if the β was broken up into $\alpha + \gamma$. There was another way of looking at it, namely, so far as the fracture was concerned. He had always found that if a mixture of metals with different constituents were fractured, and there was a fracture right through a brittle constituent metal, the colour of the fracture obtained was different from that of the cut or polished metal. That was the case in some of the tin alloys, and unquestionably in such a mixture as lead and copper. There was the colour of the lead, a greyish-white fracture, and if this alloy was polished in any way the red of the copper was to be seen; there was absolutely a different appearance. There was nothing in the paper about it, but it would be interesting to hear whether the author had observed any difference in the fracture below $470°$ and above $470°$. With regard to the illustrations at the end of the paper, which the author relied on to prove that there was the separation he had mentioned, the effect appeared to him to be simply due to the etching. He agreed with Dr. Rosenhain's remarks in that respect; in fact he went rather farther in a way, because he did not think it was a question of the mere etching up of the crystalline structure. He believed

that the structure was due to the polishing scratches. No matter how minute those were, if they were looked at in the illustrations it would be seen they were in parallel lines. He was doing some work only a day or two ago in which that very thing occurred ; he got an appearance which he thought was a structure, but it was really only a false structure. It was due entirely to the polishing material, which caused unequal pressure, and a difference of potential resulted, and so caused a structure to etch up which was a false structure. The only other point to which he wished to refer was that they had been told by Mr. Bengough that there should not be any difference of potential shown in the a metal. He did not agree with that, because as a matter of fact any a metal, although it was supposed to be homogeneous and a single constituent, was really not so unless it was annealed for a very long time. If it was not annealed for a very long time a cored structure was produced, the part that crystallised out first was richer in copper than that which crystallised out subsequently, and it appeared to him that was quite sufficient reason in itself to cause some corrosion, apart from the question of having two distinct constituents such as $a + \beta$.

Mr. E. F. LAW, Assoc.R.S.M. (London), said he had seldom heard a paper read before the Institute, or any other institute, which gave him greater pleasure. It was a very careful piece of work, clearly stated and commendably brief. While it must be very gratifying to all the members, it was especially so to those who were disciples of Roberts-Austen, who knew him and had the honour of working with him. Fourteen years was a long time in the history of their science, and it was the more remarkable that, with the appliances at Roberts-Austen's disposal, he was able so clearly to define the point under discussion. That brought him to the one criticism which he wished to make with regard to the paper. He had no hesitation in making it, because he thought the authors would readily agree with the remark he was about to make. He could have wished that the authors had not called it a new point ; personally he preferred to consider it as a re-discovery. He wished to make a suggestion to Professor Carpenter which was rather unorthodox, but he knew that gentleman would not object to it on that account. We all referred so much to a, β, γ, and so on, but personally he wanted to go beyond that, even beyond ω, to zinc. Zinc was never considered at all. It had many interesting peculiarities, but metallurgists refused to consider them. They treated zinc rather as the income tax authorities treated married women ; they said, " No, we will regard you as β, γ, and anything you like, but not as zinc." But, after all, the alloys in question were alloys of copper and zinc, and it was absolutely necessary eventually to go back to zinc. Why should we tacitly assume that zinc cannot retain its identity in solution, whereas its intermetallic compounds can ? In this connection he would like to raise the question whether intermetallic compounds did retain their identity in solution. Some did undoubtedly, but was it proved, or was it known, that all did ? It seemed unlikely, and in the absence of more definite information he always regarded intermetallic compounds as in a

rather loose state of combination somewhat analogous to double salts. It was well known that some double salts went into solution and retained their identity ; others did not, they were dissociated. Was not that the case with intermetallic compounds ? He thought the point was worth investigating.

Mr. O. F. HUDSON, M.Sc. (Birmingham), said he had read the paper with very great interest, particularly as it gave an explanation of some facts which had been recorded by Mr. Bengough and himself. The explanation the authors had given of the transformation was very ingenious, and the originality of their conception commanded respect ; but he did not know that a complete acceptance of the theory of what happened was advisable at present. Although he thought it was possible to conceive that phases would retain their individuality in solid solution, or retain a molecular individuality, he could not quite realise the comparatively gross crystalline identity which the authors seemed to insist upon. Such might be the case, but even so he was not quite reconciled to the view that the embrittling is due to the presence of γ. In the first place the authors said that it was in a very fine state of division. A brittle material in a finely divided state had not necessarily the same embrittling effect as that brittle substance when segregated in the alloy. Again, if the brittleness of the 70 : 30 brass at a temperature of 450° C. was due to the presence of brittle γ, then it seemed to him that that brittleness should remain in the cold. The 70 : 30 alloy was comparatively ductile at a red heat, and remained ductile until the red-heat stage was passed. Then it suddenly got brittle—so brittle that a piece of wire could be snapped off like a carrot, but it recovered its ductility when cold. If the change of β to $\alpha + \gamma$ had taken place in the α solid solution during cooling, then he thought the γ should remain and the material still be brittle when cold. It should be a permanent change, whereas it was not. It was only during a comparatively small range of temperature that the brass was brittle. Coming to the equilibrium diagram, the explanation given by the authors fitted in with the thermal observations. But although it was in that respect a reasonable explanation, he could not quite reconcile it with the microscopical evidence. Pure β would very easily deposit crystals of α or γ in brass on either side of the compositions, a little way removed, indicated by the points of B_4 and C_2 of Shepherd's diagram. He did not see why it should suddenly cease to deposit its α or γ over a distinct range of composition ; and he thought this was a serious objection. Finally, he desired to ask the author if he would be good enough to give as far as possible the exact details of the etching process, because personally he had found that the sort of structure shown in the photograph was so easily obtainable at high magnifications with almost any alloy.

Mr. E. L. RHEAD, M.Sc.Tech. (Manchester), said there was one point in connection with the paper in regard to which there could be only one opinion, namely, that it was an accurate record of work care-

fully done. In particular there were one or two points that were exceedingly interesting from the practical side. Since the writing of the paper two cases had been brought to his notice in which the inversion referred to was the probable cause of fracture. Calendering rolls used for embossing patterns on cloth were forced, with a considerable amount of pressure, upon steel mandrils, and a considerable pressure had to be employed for raising the pattern upon the cloth. The rolls were heated to a temperature probably of 350° or higher. They worked for a considerable period without difficulty, but in the course of a few months broke with a longitudinal crack, due to an entire change in the character of the metal owing to the prolonged heating to which they had been subjected. When that took place the metal was distinctly crystalline, and there was little doubt in his mind, although he had not had time to investigate the subject fully, that the change was directly connected with the inversion point referred to in the paper. Another case that had been brought under his notice was in connection with picture wire. Picture wire that had not been subjected to gas fumes, and which had not been even on the upper part of the room, had become brittle by very long exposure. On examining the whole of the wire he found it was in a similar condition. The change had occurred in twelve months. Whether it was due to the slow process of change closely connected probably with the low temperature inversion point he did not know, but it was somewhat interesting in that respect, and coincided with the case mentioned by the author. Another point to which he wished to refer was the definition that had been given of solid solutions. He was in agreement with most of the speakers who had preceded him, that he could not conceive the existence of separate crystals side by side as representing the solution of one substance in another. If they took the fact, as Dr. Rosenhain put it, that to get crystals formed it was necessary to conceive molecules placed in definite relationships to each other in certain groups, they might reduce the number of molecules constituting the groups to a minimum, but they must still retain that definite relationship, and he scarcely thought it a satisfactory conception to reduce the groups to one, and to consider that each individual molecule itself constituted a crystal. It appeared to him that an explanation of the condition might be afforded if they conceived that in the solid solutions, before solidification, it might be possible for the molecules to have something of the same character as they had when in a colloid form, and the possibility of remaining in a state of intermolecular distribution in the alloys appeared to him to afford probably a more ready explanation of many of the characters than separate direct crystallisation. The tendency to crystallise is so strong in many cases that the presence of large amounts of material of a foreign character may be included even when that material exists in a separate form, and has no physical character in common with the crystallising body. This occurs frequently in minerals. The point that Professor Huntington referred to about the probability of all brasses becoming brittle if that explanation be accepted, occurred to him also. In a note that he wrote at the time he mentioned that if solid

solutions consisted of individual crystals, the different expansions and contractions that must necessarily occur, when subjected to changes of temperature, owing to their difference in composition, would inevitably lead to the destruction of the strength of the metal, and the change would be quite independent of the constitution of the alloys, because it was granted that the bulk of the alloys consisted of solid solutions. That point, he thought, was certainly against the theory of the constitution as advanced.

Professor THOMAS TURNER, M.Sc., Honorary Treasurer, thought it was important in connection with the paper to distinguish between the actual practical facts and the somewhat theoretical discussion which had taken place upon them. The fact of the arrest which had been referred to taking place, and of there being a distinct change at that temperature, was one of very great importance in connection with the brass trade. He was told that practical men who were used to rolling alloys of that kind knew perfectly well that at that particular temperature they could, if they so desired, readily break a piece off, and so shape the metal. But if the metal got a little colder, it could only be fractured with difficulty. Though that had been known to practical men for many years, it had not appeared in any text-book up to the present time, and it was of importance that it should be recorded. In the next place, he wished to refer to what he regarded as a difficulty in Dr. Carpenter's theoretical explanation. As Mr. Hudson showed at a conversazione during the previous week at Birmingham, if a piece of brass wire was heated to a red heat it could be bent, but if it cooled a little below the point of red heat it could not be bent, or it could only be bent with difficulty. But when it cooled a little further it went back again exactly to its previous condition, so that it could be easily bent. If it was a question of the separation of the γ phase, and the γ remained there, it seemed to him that the metal should not recover its toughness and working properties. If it were only an allotropic or polymorphic change, the brittleness might only be temporary. For instance, at the point where γ-iron passed into β-iron there was a great weakness of the metal, as Roberts-Austen showed years ago. He was therefore rather inclined to talk about β' in the meantime, without definitely committing himself as to what β' might mean.

COMMUNICATIONS.

Dr. C. H. DESCH (Glasgow) wrote that Professor Carpenter and Mr. Edwards, by their extremely interesting experiments, had completely established the occurrence of a molecular change in many alloys of copper and zinc. Their proof that alloys containing the β solid solution underwent a well-marked thermal transformation at $470°$ was particularly interesting. It did not appear, however, that the identity of this transformation with the slow change at the ordinary temperature,

causing brittleness, had been established. The latter was common to α and $\alpha + \beta$ alloys alike, whilst the thermal change was only observed in alloys in which the β solution was present. (For reasons given below, the present writer considered it improbable that the β constituent was present in the α solid solution.) The remarkable discontinuity of mechanical properties, observed by Messrs. Bengough and Hudson in 70 : 30 brass between 400° and 500°, was, the writer believed, common to many copper alloys, whether containing the β constituent or not, and it would be interesting to determine whether any thermal change could be detected in such cases by using a sufficiently delicate pyrometric method.

The authors did not state whether the brass wire which had become brittle during storage was examined microscopically in order to prove its α character. Wire containing 36·08 per cent. of zinc might well contain the β constituent, seeing that such an alloy at 700° contained a considerable proportion of β, which would not be completely absorbed during cooling under ordinary conditions.

Of the explanations of the transformation which were discussed, the present writer preferred that represented in Fig. 7, attributing it to a dimorphism of β and β'. The fact that the change occurred at the same temperature in alloys containing respectively 45·8, 50·2, and 53·9 per cent. of zinc did not seem to be a fatal objection to this view. If the β solid solution contained a dissolved compound (the formula Cu_9Zn_8 or $Cu_{10}Zn_9$ would fit the case), it was quite likely that its transformation would occur at about the same temperature in solid solutions containing rather more or rather less zinc, the whole range of composition of the β solution at 470° being very small. The diagram below represented such a hypothetical transformation.*
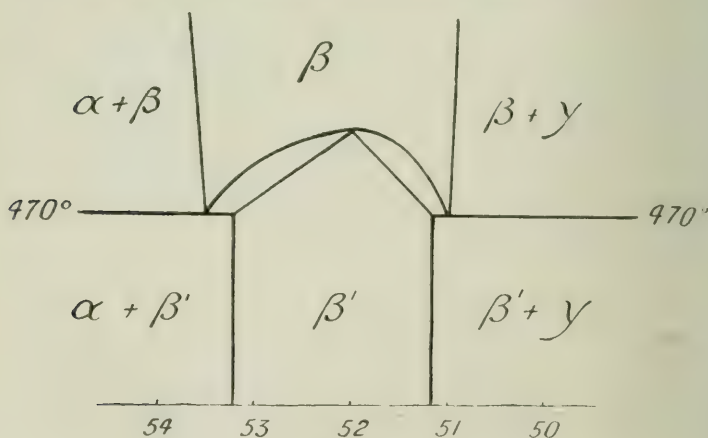
FIG. 3.

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* Should this explanation be the correct one, the transformation should occur slightly above 470° in some of the pure β alloys.

On the other hand, the supposition that the new constituent produced was γ presented several difficulties. One of these was the failure to observe any growth of the γ crystals disseminated through the mass. The evidence for a duplex structure in specimens annealed below 400° was difficult to discuss without seeing the original specimens. The photographs on Plate II. did not suggest a duplex structure, but rather an "etching-pattern" revealing the crystalline system, but it was a familiar fact that such fine structures were much less readily observed in photographs than in the course of visual examination, and considerable weight must be attached to the opinions of such skilful observers as the two authors, that the structure was really a duplex one. Thus, whilst the experimental results obtained were to be regarded as thoroughly established, it would seem well to suspend judgment as to their complete interpretation until further material was available.

He (the writer) felt compelled to dissent from the view of the nature of solid solutions expressed by Mr. Edwards in his appendix, although it appeared to have some points in its favour. That a solid solution, occurring in the middle of a series of alloys, always contained an intermetallic compound, was highly probable, as argued by Mr. Edwards, although such a view had been combated, especially by American metallurgists. The further assumption, however, that a solid solution was a minutely subdivided two-phase system, was in conflict with the doctrine of phases, and also, it would seem, with what was known of the physical properties of solid solutions of metals. The very characteristic curve of electrical conductivity, for example, could not be explained on Liebenow's assumption that the increased resistance was due to the Peltier effects at a large number of boundaries, as had been shown by Schenck and by others, and similar considerations applied to the hardness and to the thermoelectric properties. It was exceedingly difficult to form any idea of what a solution really was, but all one's experience went to show that it was something entirely different from a fine-grained mechanical mixture. The work of Messrs. Edwards and Andrew, cited in the appendix, had brought to light several facts which were of fundamental importance in any consideration of the nature of solid solutions.

Mr. G. H. Dugard (Birmingham), wrote that it seemed to him, as a practical man, that the critical point referred to was a fact that had been known and used as long as he had been connected with the manufacture of metals. When one had a thick piece of brass that it was desired to make into small pieces for melting down, it was simply necessary to get it to a black heat, when it would break quite easily with a blow from a sledge-hammer, or even upon being struck on the ground; and it was common knowledge that if it were too hot (say a red heat) it would not break. That applied to alloys containing from about 60 per cent. to 65 per cent. of copper, and, although above that percentage the metal would break, it did not become tough at higher temperatures.

He (Mr. Dugard) used that method in the manufacture of "brass solder" (which usually contained from 45 per cent. to 55 per cent. of copper). The metal was heated to a black heat, and allowed to cool

down until it was a certain colour, when it was put into the mortar, and then pounded down as fine as was required. If it were too hot or too cold, it would not pound properly.

Another instance was, when it was desired to point brass bars. A blacksmith (who was used to forging brass) would get the bars to a certain temperature (which it may be presumed would be well above the critical point, and would probably be the temperature at which it regained its ductility, as shown in Messrs. Bengough and Hudson's diagram), when he could forge the brass bar readily, but if he allowed it to get down to a black heat, the end would break off, and it became necessary for him to begin again.

There was another fact to which he would like to call attention, and that was what was known as the shaking of the richer metals. A 90 per cent. gilding metal was very subject to this, and when cast, had to be left in the ingot mould to cool. If the caster attempted to knock out the wedges, the slight jar created fine cracks in the metal, which opened the first time through the rolls, and great care had to be exercised in the annealing not to shake these rich alloys.

Referring to Messrs. Bengough and Hudson's diagram, it seemed to him (Mr. Dugard) that in annealing those alloys, if the temperature were raised to 500° C. the metal would be thoroughly annealed, and that a higher temperature would do more harm than good.

In conclusion he desired to thank the authors for their most interesting paper, and to say that that paper, and also the contribution by Messrs. Bengough and Hudson, would prove of the greatest value to manufacturers.

Dr. W. Guertler (Berlin) wrote that he wished to express his compliments to the authors on the very important discovery or re-discovery they had made on the brasses. The importance could not easily be overestimated, especially in regard to corrosion, as it was a very important matter to know if a 50 per cent. copper-zinc alloy was a homogeneous or a heterogeneous one, the latter being always more subject to corrosion by the formation of electrolytic microcells.

He thought that the proofs given of the recalescence were decisive. The differential being much more accurate than the simple cooling method, it could not be astonishing that Shepherd and Tafel could not find the tranformation points of Roberts-Austen. Especially interesting were the small recalescences in the 45 : 80 per cent. alloy at 600° and in the 50 : 20 alloy at 510° C. They seemed to correspond to the segregation of the α constituent from the β constituent with falling temperature. If so, such experiments would give a very accurate determination of the saturation curve, which, so far, it had not been possible to determine by other methods. Tracing this line, the eutectoid point of 470° would be found at 51 per cent. zinc.

As to the two possible explanations of the horizontal at 470°, the one adopted by the authors would seem by far the most plausible one. Nevertheless the proof was not absolutely completed yet. The constancy of temperature mentioned by the authors seemed to him not to be proof

enough. The single measurements were made in distances of 12° C., and so the observed constancy of temperature could not be restricted to intervals smaller than this. Besides, in cooling, the temperature was found in two cases at 457°, and in one case at 445°. Such a difference would be quite enough to allow the explanation of a transformation of the β constituent into another, β', of approximately the same composition. The micrography seemed to be very curious indeed. That Shepherd could not see the duplex structure at a magnification of 80 was not astonishing, but a magnification of, say, 500 should, as far as one's experience with analogous cases in carbon-iron, copper-tin, copper-aluminium alloys went, be sufficient to show the duplex structure with absolute evidence. Even a short annealing should develop a structure easily. It was difficult to understand why, after three weeks' annealing at 300° to 450° C., and under a magnification under 2500 diameters, the structure should not show the two constituents in absolutely sharp and conspicuous development.

As to the question of brittleness, the absence of such could not be a proof of non-existence of heterogeneity. On the contrary, it was known that a very fine duplex structure resulting from the breakdown of another crystallised phase would give most coherent bodies. This fact is well known in several cases, and especially has been confirmed lately by Professor Benedicks of Upsala.

If the horizontal really corresponded to a breakdown of β in $\alpha + \gamma$ with falling temperature, this would be done with greater facility than the reconstruction of the phase by reheating from the interacting of the two mixed phases. Therefore the recalescence temperature found in cooling (457°) would be more accurate than the one found in heating (470°), and a temperature of 460° would probably be the nearest to the truth.

As to the general question of solid solutions, Dr. Guertler wanted to add a few words as to the opinion expressed by Professor Carpenter and Mr. Edwards being contrary to what he himself said in his text-book on metallography. It was a question of fundamental importance, for most of the equilibrium diagrams of alloys which have been constructed in recent years would be wrong if transformation horizontals passed through the heterogeneous field right into the connecting homogeneous field, and traversed this also.

According to present theories, alloys were built up of different crystal-line phases, and these were built up of different kinds of molecules. Between the crystalline phase there were the laws of heterogeneous equilibrium, stating that the equilibrium was independent of the quantity of each phase present in the mixture, that the amount of phases that could be present in equilibrium was restricted to a certain number, and that the addition of a new phase to the present mixture was only possible by the extinction of one of the present phases in exchange. A discontinuity in the dependence of properties on temperature was called forth, and a concentration temperature horizontal formed. Between the molecules there were the laws of homogeneous equilibrium, stating that the equilibrium was always dependent on the relative quantities of

the different kinds of molecules present, that the number of different kinds of the same was not restricted in any way, and that no discontinuity was possible in the dependence of the equilibrium from varying temperatures, and therefore no temperature horizontal could be formed.

He agreed with Professor Carpenter and Mr. Edwards in saying that in solid solution there were present not only the molecules of the components, but also molecules of possible compounds; but the existence of compound molecules in the solid solution was not restricted to the existence of corresponding crystalline phases. It could very often be proved that intermetallic compound molecules were abundantly formed in continuous or discontinuous liquid or solid metallic solutions, even if there were no intermediate crystalline phase existing in that series of alloys.

Now the question was : The equilibrium horizontal assumed by Professor Carpenter and Mr. Edwards as traversing the α field could not be a homogeneous equilibrium of molecules, as these would not give a horizontal, previously stated. On the other hand, there could not be an equilibrium of crystalline phases in the sense of heterogeneous equilibrium, as in that case there would be no sense in the homogeneous α field and in the saturation line of this field towards the β and γ fields. Therefore, if it was assumed, with the authors, that there existed a very fine mixture of separate crystals in the one solid solution, α, there would have to be assumed a third thing between crystal and molecule. No evidence of such a thing was given, except by the osmotic phenomena. Therefore, if such a thing could be found, it would be all the more interesting, and metallurgists would be very thankful to the authors if they could provide more evidence of such a third state.

With regard to the transition points, undoubtedly existing in such copper-zinc alloys that should be entirely homogeneous (*e.g.* the alloy with 30 per cent. zinc of Carpenter and Edwards, and the alloy with 36 per cent. of zinc of Bengough and Hudson), Dr. Guertler wished to offer another explanation of the observed transition point. If a solid solution crystallised from a liquid alloy, it was known that equilibrium was not generally maintained during cooling, and only the exterior parts of the crystals would be saturated with a dissolved substance. In that case, assuming the saturation line of α in the solid state to be right, the solubility of zinc in α also increased with falling temperature. There again the saturation would not be maintained after a normal cooling following crystallisation. So, for example, an alloy with 30 per cent. zinc would not be homogeneous α, but would vary in composition from perhaps 10 to 50 per cent. zinc, and those parts containing more than 35 per cent. zinc would contain free β, and therefore make the transition point of 460° appear in the alloy. Only a very careful annealing would establish complete saturation of α with zinc, and therefore a transition point found in the alloys mentioned above would only prove this transition point to belong to the pure α, if the alloy was annealed before the experiment with the greatest care, in order to guarantee equilibrium.

Dr. A. G. C. GWYER (Birmingham) thought the authors were to be congratulated upon their results, not only from the practical standpoint, but also with respect to the light they threw upon the nature of solid solutions. He wished, however, to confine his remarks to some of the theoretical questions raised by Mr. Edwards in his appendix upon "The Nature of Solid Solutions."

Firstly, with regard to the use of the terms "mixed crystal" and "solid solution," he (Dr. Gwyer) considered that the retention of the latter term was to be recommended, especially as in his opinion its true significance was not affected by the authors' results. The term "solid solution" was the one that had been almost universally adopted by English and American metallurgists, and to discard it in favour of "mixed crystal" would inevitably lead to much undesirable confusion in the literature of the subject, apart from the undeniable fact of the somewhat ambiguous nature of the expression.

The distinction drawn by the authors between molecular structure on the one hand, and what was ordinarily understood by crystalline on the other, in its application to the case of solid solutions was a real one, but surely it applied with equal force to the case of liquid solutions, since it was equally necessary to distinguish in them between ultramicroscopic and molecular configurations or complexes. A solution was defined as "a homogeneous phase whose chemical composition and physical properties could vary continuously within certain limits and still remain homogeneous," and from that point of view Van't Hoff had drawn attention to the close analogy existing between mixtures of isomorphous substances and liquid solutions. What could, for example, be more complete than the analogy between the phenomena of diffusion in the solid state, as instanced in the absorption of carbon by iron or of lead by gold, and the corresponding phenomena between one liquid and another? It was formerly thought that chemical reactions could only occur between either liquids or gases, and that solids could not interact with one another. But the researches of Spring and others had proved that that supposition was erroneous; Spring, for instance, found that a powdered mixture of barium sulphate and sodium carbonate would interact under a pressure of 6000 atmospheres to give barium carbonate and sodium sulphate, and that the reaction proceeded after the pressure was removed. It had also been shown that the formation of a solid solution was accompanied by a change of energy; in the case of isomorphous mixtures of potassium and ammonium sulphates, for instance, the heat of formation, although not large, had been measured and found to be positive. The term "solid solution" brought out those important relations so well that it was to be preferred to the equally correct but less comprehensive one of "mixed crystal."

The term "solid solution" was, in the writer's opinion, an unsuitable one to apply to bodies such as slags and glasses, because those had come to be regarded as supercooled liquids, and hence its adoption would involve rather a contradiction in words, and also because it was not in accordance with the original and now so well-known meaning of the term introduced, in the first instance, by Van't Hoff. Since, however,

that important class of substances partook to a certain extent of the properties characteristic of true solids, especially in that they often possessed elasticity, the writer suggested the term "pseudo solid" as being a suitable one for them.

With regard to the connection between compounds and solid solutions there was much to be said in favour of Mr. Edwards' third contention, "that with the exception of the two series of mixed crystals that may be formed at each end of a series, each constituent has a compound at its foundation." The writer would like to draw Mr. Edwards' attention to the work of Lossew in the nickel-antimony series. Lossew showed (1) that nickel forms solid solutions with antimony, but that antimony does not dissolve nickel in the solid state ; and (2) that of the two compounds in the series the one. Ni_2Sb_3, forms solid solutions, not only with the neighbouring nickel-richer alloys, but also with the neighbouring nickel-poorer alloys, whilst the other compound, NiSb, forms solid solutions only with alloys richer in nickel than itself. Such behaviour would seem to be incapable of explanation were not the existence of the two above-mentioned compounds assumed to be a real one. It should not, however, be forgotten (1) that the case of mixed liquids of constant and maximum boiling-point was somewhat analogous, although it certainly was not due to the formation of chemical compounds : (2) that (approximately) simple stoichiometrical relations are often shown by eutectic mixtures, as in the copper-silver and lead-tin series, for example : and (3) that the actual proof by experiments that compounds existed under these conditions was probably unattainable, because the formation of solid solutions was known to be unaccompanied by appreciable change of volume, and hence that the effect of pressure upon their composition would be nil.

In conclusion, it should be noted that isomorphism alone was not the sole factor governing the power of certain substances to form solid solutions with one another. Tammann has pointed out that temperature was perhaps even more potent in that respect. and that it was among the elements of high melting-point that the ability to form solid solutions was most marked.

Mr. F. Johnson, M.Sc. (Swansea), wrote that he desired to express his appreciation of the discovery of the critical point in copper-zinc alloys, and to point out that ignorance of its existence must have been the cause of many mysterious failures of material in course of manufacture in works. It was the practice, after annealing brass, to transfer it to the "pickling bosh" while still hot, and it frequently happened that rods, sheets, or tubes were loaded on waggons in batches for conveyance from the annealing furnace to the "pickling bosh." At the temperature of the critical point, with which the act of dropping the material into the waggon or "bosh" must often coincide, the alloy was so "tender" that injury might frequently result. He had seen metal torn asunder when being drawn through the die, and other instances had come to his notice of metal completely failing during the process of

manufacture, of which the existence of such a critical point as that discovered by the authors could afford an explanation.

The authors mentioned that the critical point was probably responsible for the failure of brass stay-rods in locomotive boilers. Webb's experiments, * carried out on an alloy of the following composition :—

Copper									60·23
Zinc .									39·61
Iron .									·28
Arsenic									·10
Manganese									·03

showed an *accelerated* loss of tensile strength at a temperature of 400° C. and a similar loss of ductility, but there was no return of either strength or ductility beyond that temperature.

Webb gave an alloy of 91 per cent. copper, 9 per cent. zinc a very practical trial in the form of stay-rods in a locomotive boiler, and the results compared most favourably with those of copper stay-rods employed under like conditions. Apparently no such inversion as had been discovered by the authors could occur in such a dilute α solution as that alloy represents.

With regard to the specimens of brittle brass, originally belonging to Forbes, it was unfortunate that no record existed of the *condition* of the wire as manufactured. It was well known that brass which had been finished "hard" (*i.e.* hardened by mechanical treatment) was susceptible to "age-cracking" or secular brittleness, and it was possible that the specimens belonging to Forbes became brittle in that way.

Thus the question might well arise : Did the hardness or state of strain conferred by mechanical treatment favour or accelerate the velocity of the inversion which the authors suggest, viz.—

$$\alpha \rightarrow \alpha + \beta \rightarrow \alpha + (\alpha + \gamma).$$

Of the conclusions which the authors set forth on p. 149, No. 7 was rather open to dispute. The authors desired to attribute the brittleness of α alloys (*e.g.* 70 : 30 brass) at about 400° C. to their conception of the explanation of the critical point, *i.e.* to the inversion of α to α + β.

But that brittleness only existed at precisely that particular temperature, occurring neither above it, at a visible red heat, nor below it, at normal temperature.

It would be interesting to confirm that statement by quenching such an alloy at the temperature of the critical point. If the quenched material failed to retain its brittleness the authors' conclusion (No. 8) would require modification. In any case, even annealed material was subject to brittleness just above 400° C.

It would also be interesting to know if *lapse of time* only (in the case of thoroughly annealed brass) did really induce the so-called "crystallisation" or brittleness at ordinary temperatures.

* *Proceedings of the Institute of Civil Engineers*, April 22, 1902, "Locomotive Firebox Stays."

With regard to the micrographs, he (Mr. Johnson) thought it would be a good check to etch specimens of quenched β and of the annealed β for exactly similar lengths of time, using a fresh etching solution of the same strength for each specimen.   One could obtain very peculiar results by prolonged etching, and although it was not to be doubted that the structure of the annealed β was actually as shown in micrograph 2, yet further confirmation of it would be most acceptable.   He had obtained a duplex structure even in a specimen of melted cathode copper, free from oxygen, by prolonged etching.   If such pure material as cathode copper could show an apparently duplex structure, a strong solution, such as the β solution, might be expected to do so even more readily.

Mr. W. H. MERRETT, Assoc.R.S.M. (London), wrote that considerable care was taken in connection with the experimental work which was performed at the Royal Mint in the first determination of the equilibrium curve of the copper-zinc series of alloys, and he had no doubt concerning the accuracy of the pyrometric records of those experiments.   Great credit was due to Professor Carpenter and Mr. Edwards for verifying Roberts-Austen's work in this direction.   Probably the methods adopted by Mr. E. S. Shepherd for obtaining the freezing-point curves were such that would not allow of the detection of small thermal changes.   On several occasions such omissions had been detected in the work of distinguished observers.   The most minute precautions were taken in Roberts-Austen's experiments to eliminate the possible chance of small heat changes not being taken up by the thermo-couple.   Those experiments were, of course, carried out more than fourteen years ago, and it was most gratifying to one who was intimately connected with that work to find that its accuracy had been verified by Professor Carpenter and Mr. Edwards by the more delicate methods of to-day.   The fact that the authors had adopted the differential method, and had subsequently plotted the results in the form of derived differential curves from alloys containing from 54 to 46 per cent. of copper, firmly established the reliability of that portion of the work of the Institution of Mechanical Engineers' Alloys Research Committee, which was published so long ago as 1897. It was also gratifying to note that the apparent discrepancy between the results obtained by Roberts-Austen and the authors, in alloys containing from 54 to 75 per cent. of copper, was regarded by the latter as being more apparent than real.

Many of the critical points in the copper-zinc and the copper-tin series of alloys were at first regarded as eutectics by Roberts-Austen, but all attempts to squeeze them out of alloys by the method described in the Fourth Report to the Alloys Research Committee, when heated just above their critical points, failed in every case.   This led him to suspect that the changes were of the nature of a molecular rearrangement in the solid, and that liquid eutectics were not formed.

The microscopical, pyrometrical, and other evidence brought forward by the authors was conclusive, and, from a practical point of view, the investigation was of considerable importance.

Mr. Merrett further stated that he had frequently noticed that brittleness in low grade brass, and it was useful to know that, at any rate, as a temporary measure, its ductility could be restored by reheating to above 500° C.

The appendix by Mr. Edwards on "The Nature of Solid Solutions" was also of great interest, although many physical metallurgists would be inclined to dispute some of the statements enunciated. The statement that a metallic crystalline mass, often described as a solid solution, was an intimate crystalline mixture was well borne out by the fact that most of the alloys of gold and silver, when viewed under the microscope, were found to consist of a minute structure, composed of a mechanical mixture of the two constituents, gold and silver, and not of a homogeneous solution. These metals are isomorphous, and have the same atomic volume, and it was generally alleged that they formed a perfectly homogeneous mass when solid. That instance could be multiplied indefinitely; it is so even in the case of the iron-carbon alloys. The suggestion that the term solid solution should not be applied "to crystalline bodies, such as metallic alloys, but should be restricted to supercooled liquids such as glass," provided, at any rate, food for reflection.

Mr. Edwards' statement, that the mechanism of the passage of a liquid through membranes is probably dependent upon the relative sizes of the molecules in the solution and the pores of the membrane, and that the action of the membrane is that of an exceedingly fine sieve, was of great interest, and undoubtedly was correct. Such separations were well known in the animal kingdom, but in the case of fused metals they naturally seldom occurred. However, the mechanical separation of the constituents of a fused mixture of metals was not unknown.

For instance, the experiments of Warburg and Tegetmeier, which were repeated by Roberts-Austen in 1893 or thereabouts, threw considerable light on that phenomenon. He demonstrated the possibility of eventually producing a degree of porosity in vitreous bodies which would admit the passage of metallic elements having low atomic volumes, while other metallic elements having larger atomic volumes were strained off, thus bringing about a mechanical sifting of the metallic elements. A receptacle was divided by a sheet of glass, sodium amalgam being placed on one side and pure mercury on the other; the whole was then heated to 200° C., at which temperature the glass became slightly conducting. One terminal was placed in the amalgam and the other in the mercury, and an electric current with a difference of potential of about 10 volts was passed for thirty hours. At the end of that time it was found that a considerable quantity of sodium had passed into the mercury, which was originally pure. A corresponding amount of sodium had been lost by the amalgam, and the glass septum had preserved its original weight and clearness. However, when the sodium amalgam was replaced by lithium amalgam and the experiment repeated, it was found that the sodium of the glass passed into the originally pure mercury, and the glass became opaque and friable on the side touching the lithium amalgam. The conclusion made was that the atoms of lithium having an atomic volume of 15·98 could pass along the molecular galleries left in the glass by the

sodium atoms, the atomic volume of the latter being 16·04. When, however, a metal of greater atomic volume than sodium was substituted for lithium, it then appeared that its atoms would not pass through the tracks left by the sodium, the new atoms being too large to pass through the spaces where the sodium had been.

He (Mr. Merrett) congratulated the authors on their paper, which he considered was of great practical value.

Sir GERARD MUNTZ, Bart., President, wrote that he was of the opinion that the title of Professor Carpenter and Mr. Edwards' paper needed amending. To any one who had been actively engaged in the manufacture of any article made of brass there was nothing new about this so-called " new critical point."

A more correct title for the paper would have been, " A Suggested Interpretation and Explanation of the Black-hot Breaking-point in Brass Alloys."

Speaking with nearly thirty years' experience of the manufacture of brass, he might say at once that the critical point at a black heat in brass alloys had been not only known to himself, but had been accepted as a practical fact to be used or avoided as the case might necessitate. In rolling sheets of Muntz metal it was used for breaking off the tag ends, which could be done with a light blow of the tongs at the proper heat, also for separating the sheets, which were always rolled double in pairs, thus having one end joined.

In the rolling of the sheets it was known that sheets must *not* be rolled at a temperature *below* the black breaking-point or they would break, though after the metal was cold it might safely be cold-rolled, and was perfectly tough and ductile.

In the rolling of rods the black breaking-point was also a feature. If an attempt were made to hot-roll rods at too low a temperature the surfaces of the metal would at once show cracks, and if the process were carried to any extreme the metal was completely broken up and rendered useless. It was the narrowness of margin between the highest temperature at which β brass could be safely hot-rolled and the black breaking-point which had always rendered the continuous rolling-mill, commonly used for copper, almost impossible for use with brasses.

In the manufacture of heavy brass pump-rods or shafts, the black breaking-point was used for cutting the rods to dead lengths. To shear rods from 3 inches to 9 inches diameter with square ends would be practically impossible; and to cut them off with a hot saw would be expensive both in saws and swarf. Instead of this the rods were, whilst hot, nicked round with a set and sledge hammer. The rod was then supported on a small block, just inside the neck, and, at the proper temperature, a quite light blow from a hammer would break off the end, leaving a clean, square end. In the manufacture of brass tubes of 70 : 30 alloy care had to be taken, during the process of annealing, not to attempt to move the tubes at the black breaking-point. If an attempt were made to lift them with tongs at that temperature, it would be probable that a piece would break out and come away with

the tongs. If the tubes were lifted, just above the critical point, and then handled roughly in setting down, it was more than likely that cross and longitudinal cracks would be developed. All the above matters were well-known practical facts, and there was not, and scarcely ever could have been, any question, in the mind of a practical worker in brass, as to the existence of a critical point. What the practical man would possibly find useful was the "reason why." What happened in the alloy at this temperature to render it brittle as glass, and why should it recover its strength at a temperature very little below that point? The latter recovery was also an undoubted fact. An inexperienced workman would sometimes wait just a little too long before trying to break off, and the result was that he failed to break at all, and was in great trouble, the metal then having to be cut through cold, a very long and tedious business.

Professor Carpenter and Mr. Edwards' theory of the change from β to $\alpha + \gamma$ was interesting, but in itself it was not sufficient. To begin with, could any scientists as yet tell exactly what were the relative proportions of copper and zinc in either α, β, or γ? It was known that, in certain mixtures of metals, there was obtained a certain class of crystal formation; but why were there two classes of crystals in some alloys, and apparently only one in others? Professor Carpenter had demonstrated that at 2500 magnification much could be seen that was not visible at 80. Might not yet more be shown with higher magnification? Were any of the alloys truly homogeneous, or were they not all very intimate mixtures of copper and zinc in different proportions? Professor Carpenter suggested that the presence in 70 : 30 brass condenser tubes of copper and γ, the latter being electro-positive of the former, was sufficient to account for corrosion. But why not copper and zinc? If γ were a homogeneous substance, how was the absolute dezincification of brass in sea-water to be accounted for?

The theory of the conversion of β into $\alpha + \gamma$ at about 470° was ingenious; but, might not the critical point have something to do with the melting-point of zinc? That had always seemed to him (Sir Gerard) to have something to do with the matter. It was at least curious that this phase should so nearly coincide with the melting-point of zinc; and further, that there should be a slight difference between the black breaking-point of various brass alloys. Had not the proportion of copper and zinc some bearing on that point?

Another point, of very practical interest, was the effect of hot-quenching brass alloys. It was an undoubted fact that all the so-called β brasses had their tensile strength and elongation considerably improved by quenching at a red heat. The exact point at which the best results were to be obtained required experience, and there was a marked variation; yet, if the quenching merely resulted in obtaining the β phase, and preventing the development of γ, they were at once brought back to the authors' other theory, of the change wrought by time; and it would be of interest to know whether later on, in spite of the artificial suspension of the change, time would not cause the recrystallisation of the brass to take place, with disastrous results.

He (Sir Gerard) considered that the suggestion that time-crackings and a black-hot fracture arose from the same cause must be accepted with caution. Beyond those were the questions of fire-cracks and of weather-cracks ; and the undoubted fact that brass, in a hard state, was much more liable to time and weather-crackings than was unannealed brass. The effect of work on the crystal formation was, in his opinion, a matter which must be considered separately from the question of the critical temperature point.

There were two critical points to be watched in handling brasses hot. That at about 470° C., near the melting-point of zinc (433° C.), and a hot breaking-point about 900° C., which was, oddly enough, nearly the boiling-point of zinc (920° C.). In practice they were Scylla and Charybdis to the workman.

The best temperature for hot treatment of brass alloys was between 500° C. and 650° C. The only effective temperatures for zinc distillation were between 415° C. and 550° C., this being yet another point that might be worth the scientists' consideration. It might be left to their scientific brethren to fight out the question as to whether it were possible to detect the critical point by the pyrometer, or whether the lines of Shepherd's diagram should, or should not, meet. Also, they would have to decide whether they should call the brittle phase $\beta + \gamma$ or $\alpha + \gamma$. "What's in a name? A rose by any other name would smell as sweet !" So, too, speaking as a manufacturer, it mattered little what theoretical formula was given to it. They knew there was a critical phase in brass, and they would like to know the "reason why."

The members of the Institute of Metals, and all manufacturers of brass goods, ought assuredly to be highly grateful to Professor Carpenter and Mr. Edwards for starting a discussion on this subject. It was sincerely to be hoped that their further investigations in this direction might throw yet more light on what as yet remained obscure and problematical.

Professor CARPENTER and Mr. EDWARDS, replying in writing both to the discussion and correspondence, thanked the various gentlemen who had contributed so many interesting and valuable expressions of opinion on their paper, particularly on its speculative and theoretical aspects.

1. It was not to be expected that anything like a consensus of opinion in regard to these would be obtained. What had been realised, however, was something more useful, viz. a full, critical, and many-sided discussion of a novel theoretical view which the authors' experiments had led them to put forward. So far as these criticisms dealt with the subject-matter of the appendix by Mr. Edwards, a separate reply by him would be found at the conclusion of the present reply (p. 193).

2. It was satisfactory that the experimental data quoted in the paper which formed the basis of the authors' theoretical reasoning were accepted as fully established by every one who had taken part in the discussion and communications. Indeed the "critical point" appeared to be so thoroughly made use of in works practice (cf. the communications by Messrs. Dugard, Johnson, and Sir Gerard Muntz) that the last-named

was of opinion that the authors' designation " new " was unsuitable, and that a more correct title for the paper would have been " A Suggested Interpretation and Explanation of the Black-hot Breaking-point in Brass Alloys." Another criticism of the title from a more purely scientific standpoint had been made by Mr. Law, who, in view of the close relation of the paper to the Fourth Alloys Research Report by the late Sir William Roberts-Austen, considered that " re-discovered " would have been a more correct designation than " new."

3. The authors did not desire to express any disagreement with either of these opinions. At the same time they wished to point out that they predicted the existence of the critical point from certain theoretical considerations, and established it experimentally before they noticed the line $e''\ e'$ in Roberts-Austen's diagram. Moreover, from the physico-chemical standpoint it could not be contested that the critical point was new, and that it furnished a new scientific explanation of a well-known practical phenomenon. They thought therefore that these constituted adequate reasons for the title they had originally chosen.

4. Some of the contributors apparently preferred an interpretation of the thermal change in β at 470° C., which was first considered by the authors but rejected by them after full consideration, viz. that it is a polymorphic change. Among those who held this view were Messrs. Rosenhain, Turner, Desch, and apparently Hudson, although the last-named did not, in so many words, commit himself definitely to this interpretation. The authors' explanation of the change as a resolution of β into $\alpha + \gamma$ on cooling was accepted as the more probable by Messrs. Bengough, Guertler, and Merrett. The criticisms under this head would now be considered in detail.

5. Dr. Rosenhain criticised the authors' interpretation of the critical point because the evidence for rejecting the idea that the thermal inversion was due to a polymorphic change in the β constituent was based upon heating and cooling curves of only four alloys, one of which did not show it at all. He also pointed out, what is indeed obvious from the curves, that the peak in two of them occurred at 457°, and in the third at 445° C., and concluded that the temperature of the inversion is not constant. He also considered that a greater number of curves should have been taken, and that the evidence for rejecting the idea of a polymorphic change was insufficient as it stood in the paper.

6. It was perhaps a pity in making this criticism that Dr. Rosenhain omitted to take into consideration the uniform results shown on the heating curves where in each case the peak occurred at 470° C. Owing to the liability to supercooling of alloys at these comparatively low temperatures, the authors were disposed to place more reliance on the heating curves, and it was for this reason that they concluded that the inversion took place at a constant temperature, and that they gave 470° C. as the temperature of the critical change as shown on the heating curves, and not 457° as shown on two out of the three cooling curves. In this connection an interesting point had been raised by Dr. Guertler, who suggested that "if the horizontal really corresponded to a breakdown of β into $\alpha + \gamma$ with failing temperature, this would be done with greater facility

than the reconstruction of the phase by reheating from the interacting of two mixed phases. Therefore the recalescence temperature found in cooling (470°) would be more accurate than the one found in heating (470°), and a temperature of 460° would probably be nearer the truth." This suggestion, based on perfectly sound reasoning, the authors were ready to accept.

7. They agreed with Dr. Rosenhain's suggestion that it was usually advisable to take more heating and cooling curves than they had done in the present paper, but in this case, and not considering for the moment the suggestion made by Dr. Desch, they were of opinion that the evidence was quite sufficient. It was quite clear that the thermal inversion occurred in the β constituent. In order to test if its temperature was influenced by the composition of β, it was only necessary to determine that temperature when β contained its maximum and minimum amount of copper. If no difference was found this proved that the composition had no effect on the temperature of the change. As against this, however, there was the possibility of a change taking place in accordance with the diagram introduced by Dr. Desch (Fig. 3, p. 172).

8. Messrs. Rosenhain, Huntington, Desch, Hudson, and Johnson were all sceptical as to the evidence for the duplex structure of β given in the paper. The grounds for this scepticism were perfectly valid. The point was a very difficult one to establish, and the evidence of microphotographs was hardly sufficient. What was required was a careful visual examination of the constituent at a magnification of at least 1000 diameters. It was only after prolonged visual examination of this kind that the authors themselves concluded that the so-called β was an inhomogeneous material. There seemed to be an impression among the sceptics that because the structure of β as shown in photomicrograph No. 2 resembled that of a deeply-etched crystalline aggregate, that it was necessarily the same thing. Professor Huntington went even further, and considered that the structure shown was due to the polishing scratches. This, of course, would have been a very serious and very elementary mistake to make, and the authors would like to assure him that every care was taken to eliminate the last trace of scratches before etching the polished surface. With regard to Mr. Hudson's point, the specimens were etched (for the most part lightly) either in dilute ammonia containing hydrogen peroxide or in a hydrochloric acid solution of ferric chloride.

9. An important objection to the authors' theory was raised by Messrs. Rosenhain, Desch, and Guertler in directing attention to the non-coalescence of the $\alpha + \gamma$ mixture even after the three weeks' annealing at from 350° to 400° C. In answer to this, the authors did not wish to convey to the minds of readers the impression that the crystals would not grow at all, but merely that after annealing for the period mentioned no marked coalescence of the decomposition products of the inversion could be observed with certainty. They agreed with these gentlemen that aggregation must take place if their interpretation of the change was correct, but they desired to point out that the molecular mobility of the mass must be low at temperatures below 470° C., and for that reason time must be a very important factor. In such cases as the iron-carbon, the

copper-tin, and the copper-aluminium alloys which have been quoted, the inversion occurs at considerably higher temperatures, but even in the last-named case Curry had shown that it was necessary to anneal for six weeks before the constituents completely aggregated.

10. With regard to the connection suggested by the authors between the mechanical properties of the α brasses and the β inversion, Dr. Rosenhain denied this altogether. He said, "No connection had been established in the paper, and he thought there was very grave reason for doubting whether there could be any." In reply, the authors did not claim that the connection had been experimentally established, but their suggestion furnished an explanation of the remarkable change in the mechanical properties of the α brasses when passing through temperatures in the neighbourhood of $450°$ to $470°$ C.—a change for which hitherto no explanation has been forthcoming. The coincidence in temperature may be accidental. It was open to any one to say this, but it was significant that Mr. Bengough, whose knowledge of the properties of the brasses entitled considerable weight to be attached to his opinion, said that "he was prepared to accept the change as interpreted by the authors as almost certainly the most probable one," thereby admitting the connection. Professor Huntington also agreed with the connection between the two sets of data.

11. The authors were not unnaturally very gratified at Mr. Bengough's communication for two reasons. Firstly, because among the fourteen contributions it was the only one which was completely favourable; and, secondly, because he furnished particulars of two sets of experiments which had an important bearing on the question of the correctness of their interpretation of the inversion in the β constituent. They were glad he had been able to clear up the slight discrepancy between his and their temperature measurements of the inversion. His experiments with a Δ-metal containing aluminium, iron, and manganese, and the enormous elongation found on passing from $500°$ to $520°$ C. were in complete agreement with some experiments on the inversions in aluminium brasses by one of the authors (Professor Carpenter) which will be published in due course. There was a well-marked thermal inversion in these alloys close to the temperature given by him, showing that aluminium *raises* the temperature of the inversion. This was an important piece of evidence in favour of the authors' interpretation of the inversion at $470°$ C. If it were merely a polymorphic change of β into β', the temperature would certainly not be raised by the addition of a third element, but, on the contrary, lowered. On the other hand, the investigation of Messrs. Andrew and Edwards [*] had shown that 1 per cent. of tin immensely accelerated the inversion of copper-aluminium β into $\alpha+\gamma$, and it would be a strictly analogous case if aluminium were found to expedite the inversion of the copper-zinc β into its decomposition products.

12. Mr. Bengough's experiments on the equilibria between α and β in a Muntz metal at various temperatures and the temperature at which β should entirely disappear were of the greatest interest to the authors,

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[*] *Journal of the Institute of Metals*, 1909, vol. ii.

as they constituted a perfectly independent line of evidence on the matter under consideration, and were in harmony with their own results. Of special interest was his success in obtaining much clearer microscopic evidence than they had done of the breaking down of the β constituent in a specimen of Muntz metal annealed for a fortnight at 440° C. He appeared to have found in a 25 per cent. aqueous solution of ammonia a more satisfactory etching material than those used by the authors, and they would experiment with it on their own specimens.

13. Professor Huntington criticised the authors' theory from the standpoint of practical experience. He said : " If the authors' conclusions meant anything they meant that all copper-zinc alloys given sufficient time would become brittle . . . for all practical purposes they knew that the alloys gave an elongation of anything they liked from 20 per cent. to 40 per cent. or more under normal conditions in everyday work. Personally he could not understand where the brittleness came in. There were thousands and thousands of tons of those materials in existence in the world, and for every 1000 tons in use how many tons or fractions of a ton did they hear about as being brittle? Of course he did not dispute that brittle material was sometimes obtained, but Professor Carpenter's statement would imply that it was an everyday sort of thing to have the usual metals with which engineers worked in a brittle state. As a matter of fact this was not the case. The paper rather staggered one at first." In rejecting this *reductio ad absurdum* it appeared to the authors that Professor Huntington had to some extent misapprehended the bearing of their theory on the everyday behaviour of brass. The crux of the matter was the answer to his question, " What was sufficient time ?" The ordinary cast Muntz metal was a metastable alloy, and it was by no means improbable that the 70 : 30 brass came into the same category. In this condition these alloys were satisfactory ductile materials, and on account of the very slight molecular mobility at the ordinary temperatures, by far the greatest proportion of the total quantity made, remained for an indefinite period (reckoned from a practical standpoint) and thus preserved its ductility, as Professor Huntington pointed out. Various causes, however, were liable to act which operated in the direction of causing the metastable to pass into the stable phase with a consequent diminution or disappearance of ductility. Of these probably the most potent was the presence of certain impurities, though nothing was as yet known as to their nature. These would be responsible for the cases of secular brittleness and ageing which arose from time to time and caused the fractures which were spoken of as mysterious. Mr. Bengough quoted evidence to show that in " highly worked brass " the change was liable to be expedited owing to the mechanical work put on the alloy. This was, therefore, another possible agency at work. Accordingly, they considered that their theory was in harmony with the results of everyday experience with brass alloys.

14. Professor Huntington pointed out that brasses containing 36 per cent. of zinc were liable to obtain appreciable amounts of β even after annealing. This was quite true. Dr. Desch drew attention to the same point, and alluded to the fact that "such an alloy at 700° contained a

considerable proportion of β which would not be completely absorbed during cooling under ordinary conditions." Forbes' brittle wire had been microscopically examined, but not a trace of β could be detected. Accordingly, even if the original wire contained some of this constituent, either subsequent heat treatment or the long period since its manufacture sufficed for its complete absorption.

15. Professor Huntington raised the objection that if the authors' theory were correct it would be impossible for the β structure to be developed by the etching of an annealed specimen. He said, " It would be found that at 1000 diameters, and' not above 470° C., β crystals were quite distinctly shown which should not be the case if the β was broken up into $\alpha + \gamma$. The answer to this was that even after the inversion the $\alpha + \gamma$ complex retains the boundaries of the original allotrimorphic β crystals which are developed by etching whether above or below 470° C.

16. The point raised by Professor Huntington as to the fractures was of considerable interest, but the authors were not in a position to give any information on this point at present. His last point as to the inhomogeneity of any unannealed α metal was quite correct and was indeed a well-recognised fact, and its influence on the liability to corrosion of any metal must be submitted.

17. Mr. Law considered the fact that zinc was a constituent of these alloys was often lost sight of. He said, " Zinc was never considered at all. It had many interesting peculiarities, but metallurgists refused to consider them. . . . After all the alloys in question were alloys of copper and zinc, and it was absolutely necessary eventually to go back to zinc. Why should we tacitly assume that zinc cannot retain its identity in solution whereas its intermetallic compounds can ? " Mr. Law's point was no doubt true, at least to some extent. But in spite of the fact that zinc was one of the components of the series it was necessary that zinc *qua* zinc should be ignored when considering only the α and β constituents at the copper end of the series, for whilst the properties of the alloys containing α and β were modified by the percentage of zinc present, *zinc could not retain its identity in these constituents.* The question of a metallic element or compound retaining its identity could only apply to the constituent to which it was adjacent in the series. Zinc does not occupy this position in regard to α or β. In the present instance, therefore, Mr. Law's point was irrelevant. If this were not so, of what use would an equilibrium diagram be ?

18. Mr. Hudson and also Professor Turner advanced an argument against the critical point being regarded as a decomposition of β into $\alpha + \gamma$, and stated it in such a subtle way as almost to carry conviction. The former said, " If the brittleness of the 70 : 30 brass at a temperature of 450° C. was due to the presence of brittle γ, then it seemed to him that that brittleness should remain in the cold. The 70 : 30 alloy was comparatively ductile at a red heat, and remained so until the red heat stage was passed. Then it got suddenly brittle—so brittle that a piece of wire could be snapped off like a carrot, but it recovered its ductility when cold. It should be a permanent change, whereas it was not." The latter added, " If it was a question of the separation of the γ phase, and

the γ remained there, it seemed to him that the metal should not recover its toughness and working properties. If it was only an allotropic or polymorphic change, the brittleness might only be temporary." Plausible as the argument sounds, it could be applied with just as much force against the explanation suggested by Professor Turner. Whatever explanation of the critical point was suggested it was difficult to give a satisfactory answer to the question, "Why is the 70 : 30 brass brittle at 470° C. and ductile both above and below this temperature?" The following explanation, however, appeared to the authors to be in harmony with their theory and the observed facts.

Consider a brass wire of the above composition cooling from 600° C. From this temperature down to 470° C. dissolved β was the stable phase and the alloy was ductile. At 470° C., although the change could not be pyrometrically determined, this resolved itself into a fine complex of α + γ. At this temperature, therefore, there was a complete revolution in the constitution, and it was quite intelligible with a complete absence of cohesion between the two constituents at the moment of their formation, one of which was admittedly brittle, that the alloy should entirely lose its mechanical strength and exhibit the well-known brittleness. On cooling below this temperature, however, contraction set in, cohesion between the α and γ was restored, and this increased the further the temperature was removed from 470° C., so that in due course mechanical strength and ductility were recovered. Speaking generally, it appeared to the authors that mechanical weakness might be anticipated at the inversion and transition points of all metals and alloys, and that it was more likely to occur in cases such as the above where a homogeneous material was resolved into a complex of two phases than in the case suggested by Professor Turner where one polymorphic form passed into another.

19. Mr. Hudson thought a serious objection to the authors' theory was that there seemed to be no reason why β should suddenly cease to deposit its α or γ over a distinct range of composition. So far from this being the case it was just what was to be expected *a priori,* and indeed the copper-zinc alloys had hitherto always been held up as an example of a departure from the general rule.

20. The authors were obliged to Mr. Rhead for his interesting communication and the practical illustrations he quoted on which the critical point had a considerable bearing ; also to Dr. Desch for his diagram, Fig. 3, representing the change on the supposition of the dimorphism of β and β'. His various points had been dealt with in sections 4, 7, 8, 9, and 14.

21. The communications of Mr. Dugard, Mr. Johnson, and Sir Gerard Muntz made it quite clear that the physical change in brasses at 470° C. was made abundant use of in industrial operations. At the same time they brought to light another case where practice had been ahead of science for many years. With reference to Mr. Dugard's suggestion that 500° C. was a sufficiently high temperature for annealing brasses, and that a higher temperature would do more harm than good, the authors would venture to point out that on account of low molecular mobility at this

temperature a very much longer annealing would be required than at, say, 600° or 650° C. In addition, the brass was liable to deteriorate under the influence of heating gases, so that, all things considered, it appeared to them that the shorter period at the higher temperature mentioned was preferable from a practical standpoint. They understood that this temperature was very near to that recommended by Messrs. Bengough and Hudson as a result of their researches. Theoretically, however, Mr. Dugard's suggestion was perfectly correct.

22. With reference to Dr. Guertler's most interesting contribution, certain of his points had been dealt with in sections 6 and 9. His interpretation of the small peak on the cooling curve of No. 2 alloy at 600° was quite correct, viz. the beginning of the separation of a. In the case of No. 3, however, the peak at 510° C. corresponded to the separation of a small quantity of γ. As he pointed out, this method permits of an accurate determination of the saturation curve. His criticism of the extent to which the authors had proved the constancy of temperature of the inversion was perfectly valid. They would refer him, however, for a complete answer to his question contained in section 6. His remarks as to the inhomogeneity of a, unless it had been very carefully annealed, and its bearing on the question of the β inversion in such an alloy, appeared to them perfectly correct. His contribution had been most helpful and illuminating on the theoretical side.

23. Mr. Johnson raised an important point in regard to the condition of Forbes' brittle wire, viz. the effect of mechanical treatment on the velocity of the inversion $\beta \rightarrow a + \gamma$. Unfortunately no record of the required information had been found. Such knowledge as was available appeared to point to severe mechanical work expediting the change (*cf.* section 13). He appeared to doubt whether there was any connection between the critical point at 470° and the brittleness of a brass (70 : 30) at 400° C. He said, "That brittleness only existed at precisely that particular temperature, occurring neither above it at a visible red heat nor below it at normal temperature." So far as the authors knew the lower limit of the brittle zone had never been determined, but that it extended to 400° C. was shown by the experiments of Bengough and Hudson (*cf* page 17). Their diagram showed that at 400° C. the ductility was no more than 1·5 per cent.; even at 310° it was only 2·5 per cent. It was clear therefore that the brittle zone was of considerable area, and that it was not confined within a very narrow temperature limit as Mr. Johnson attempted to insist. Mr. Johnson's final point had been dealt with in section 8.

24. The authors were very glad they had extracted the contribution by Mr. Merrett, who had assisted in taking the curves mentioned in the Fourth Alloys Research Report, which led to the introduction of the line $e'' e'$. With rare unselfishness he made the most modest reference to the fact that he had shared in this important pioneering work.

25. With regard to Sir Gerard Muntz's criticism of the title of the paper, this had been dealt with in section 3. He gave a variety of interesting examples of the way in which the critical point has for many years been used in industrial practice, and concluded by saying, "There

was not, and there scarcely ever could have been, any question in the mind of the practical worker in brass as to the existence of a critical point. What the practical man would possibly find useful was the 'reason why.' What happened in the alloy at this temperature to render it brittle as brass, and why should it recover its strength at a temperature very little below this point? . . . The authors' theory of the change from β to $\alpha + \gamma$ was interesting, but in itself it was not sufficient." He then put certain questions which the authors would endeavour to answer.

26. (1) " Could any scientists as yet tell exactly what were the relative proportions of copper or zinc in either α, β, or γ ? " The answer was, certainly. It was exactly the information that the equilibrium diagram gave. The proportions depended on the temperature to a greater or less extent, but taking 500° C. as an instance, they were as follows:—

> α contained anything up to 36 per cent. of zinc,
> β ,,   from 46 to 47   ,,   ,,
> γ ,,   from 60 to 69   ,,   ,,

the remainder being copper.

27. (2) " It was known that in certain mixtures of metals there was obtained a certain class of crystal formation ; but why were there two classes of crystals in some alloys and apparently only one in others ? " The answer to this was that it all depends on the mutual solubility of the two metals. Iron and nickel dissolved in one another in all proportions, and gave only one type of crystals, no matter what the proportions. On the other hand, copper and zinc were not mutually soluble in all proportions. Starting from copper and adding zinc, the limit of solubility was reached with 36 per cent. of the latter. Up to this point only α crystals were observed, beyond it β crystals appeared with the α.

28. (3) " At 2500 magnifications much could be seen that was not visible at 80. Might not yet more be shown at higher magnifications ? " Undoubtedly the answer must be in the affirmative.

29. (4) " Were any of the alloys truly homogeneous, or were they not all very intimate mixtures of copper and zinc in different proportions ? " Given sufficient annealing, the answer to the first part of the question was " yes." Any given alloys, however, contained both copper and zinc as such. It might contain one of them as such, together with the other in the form of a dissolved compound whose composition might vary within certain limits. This state of affairs applied more particularly to alloys at the ends of the series. The middle members, however, contained neither of the metals as such, but in more complex forms, which had a compound as their basis.

30. (5) " The authors suggested that the presence in 70 : 30 brass condenser tubes of copper and γ, the latter being electro-positive to the former, was sufficient to account for corrosion. But why not copper and zinc? If γ were a homogeneous substance, how was the absolute de-zincification of brass in sea-water to be accounted for ? " The answer was that zinc as such, either segregated or dissolved, could not be present in 70 : 30 brass, but that it existed in a combined form with copper. Accord-

ing to the authors' theory it was present as γ. This gave all the necessary conditions for the complete dezincification of condenser tubes in sea-water which was found.

31. (6) " Might not the critical point have something to do with the meeting-point of zinc ? " The answer was that as zinc was not present as such, there was probably no connection at all, in spite of the fact which Sir Gerard Muntz pointed out, that the temperatures of the two were near together.

32. He also referred to the " hot breaking-point " of brass at about 900° C., and said that it was " oddly enough near the boiling-point of zinc, 920° C." This coincidence also was probably purely accidental, for the reason given in section 30. The real reason was given in the equilibrium diagram, from which it was clear that at 900° C. the solidus line had been passed and liquefaction had begun. It was the presence of fluid particles in the alloy at this temperature which was responsible for the hot breaking-point.

33. Finally, he said, " They knew there was a critical point in brass, and they should like to know the ' reason why.' " The authors hoped, as a result of their investigations, the discussion and communications, and their reply, that Sir Gerard Muntz would be able to obtain an answer to his question. It was their opinion that considerable information on this point had now been obtained. Their experimental facts had been accepted by every one who had taken part in the discussion and communications. Their theory, although only accepted by some, they thought still held the field. If he chose to accept it, then he obtained an answer to his question.*

Mr. EDWARDS wrote, thanking Drs. Rosenhain, Desch, Guertler, Gwyer, and Mr. Merrett for their valuable criticism of his views of the " Nature of Solid Solutions." The criticisms of those gentlemen were so varied and serious that it was practically impossible to deal with them in the form of a reply in the time allowed the author.

What he (Mr. Edwards) proposed to do was to discuss the matter again in the form of a short paper, and develop the items to which objection had been raised. The great advantage in favour of this was that members would have the opportunity of again discussing the author's views, whereas if he now replied the matter would be closed.

The paper had already given rise to a remarkably good discussion and expression of ideas, which was a good step towards the solution of any problem.

NOTE BY PROFESSOR CARPENTER.

* Mr. Edwards has recently accepted an appointment which has necessitated his leaving Manchester, and the severance of our connection in this work. I am investigating certain points arising out of the above investigation. In particular I am endeavouring to obtain more decisive microscopical evidence of the meaning of the inversion at 470° C., and to prevent the inversion taking place by experimenting with the introduction of some one element or elements into the copper-zinc alloys.

SOME TESTS ON WHITE ANTI-FRICTION BEARING METALS.*

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An appeal made to manufacturers by the first President of the Institute, Sir William White,* following the reading of a paper on the "Elastic Breakdown of Non-Ferrous Metals" by one of the present authors, was one of the factors which induced the second author of the present paper to approach the writer of that paper suggesting certain research work in a somewhat different direction to that which had already been pursued in testing white anti-friction bearing metals.

At the outset it will be well to refer to one of the difficulties connected with the question of publishing the results of these experiments. The directors of the manufacturing company whose metals are chiefly the subject of the present paper were naturally not prepared to disclose to the public the precise formulæ of the alloys under test. It was decided, therefore, to select as a standard of comparison a published formula of undoubted value. The standard metal of the Italian State Railways, referred to under the mark F.D.S. (Ferrovie Della Stato)—for which the manufacturers in question have executed some large contracts—was selected as such standard of comparison. The reason was that it closely approximates to the formula selected by Charpy for that alloy which has little brittleness with high resistance to compression.†

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* Read at Annual General Meeting, London, January 18, 1911.

* *Journal of the Institute of Metals*, vol. ii., 1909, No. 2, p. 216.

† "L'étude sur les alliages blancs dits antifriction," *Contribution à l'étude de alliages*, 1901, p. 203. Paris, Chamerot et Renouard.

The formulæ are as follows :—

				Per Cent.	Per Cent.	Per Cent.
F.D.S.	.	.	.	tin 83·0	antimony 11·0	copper 6·0
Charpy	.	.	.	,, 83·33	,, 11·11	,, 5·55

Four other alloys were selected for comparison with the standard. The chief difference between the standard and the four comparative alloys is, that, in a gradually extending degree, the 83 per cent. of tin in the former is replaced by lead in the latter. There is, of course, such re-arrangement of the antimony and copper proportions as experience has shown to be desirable where lead enters into the composition. It may be said, however, that even in the alloy poorest in tin a very substantial percentage of that metal is present, and this paper does not profess to deal with lead basis alloys at all, although such alloys undoubtedly serve a useful purpose in engineering practice.

It will be seen from the results given, that in some of the tests the most expensive alloy—that containing no lead—does not show the best results.

So far as could be ascertained, there seems to be no standard mechanical tests for bearing metals, and the chief object of the present paper is to promote a discussion which will give some indication of the tests which practical men think are most suitable.

Steel users insist upon certain physical tests in addition to chemical analysis, and it would seem to be advantageous for some standard to be set for similar tests for the guidance of white metal users.

The most obvious test for a bearing metal is one which reproduces as nearly as is possible the actual conditions under which the material is used. Unfortunately, such conditions are very difficult to reproduce in a number of tests so as to give comparative results, and it was therefore considered better to obtain the views of the members of the Institute on this and other matters before undertaking a long and possibly expensive series of tests.

It is essential for commercial tests to be able to repeat easily the condition under which the experiments are made. Among the variables which obtain with friction tests—other

than the materials tested—are the quantity and quality of the lubricant, the temperature, and the " bedding in " of the bearing.   Moreover, it is considered that, although it may be possible to overcome some of these difficulties in a college laboratory, such tests are not suitable for commercial purposes. They are obviously more expensive than static tests.   It must also be stated that there is at present no apparatus at the disposal of the authors for making these tests.   It is, however, probable that, should the members of this Institute think them necessary, arrangements could be made for the subject to be fully investigated.   It should be remembered, moreover, that the primary object of this paper is to obtain a discussion on commercial methods of testing bearing metals.

It is obviously essential that a bearing metal should be strong and tough in order to withstand high pressures. There are also the questions of its durability, ease in fixing and replacing, corrodibility, and cost.

Mechanical Tests.

The results of the various tests are given below, and great care was taken to ensure that all specimens were tested under almost exactly similar conditions.   Thus the time of loading, the method of gripping specimen, &c., were carefully considered.

Ingots were supplied bearing five different marks :—

> F.D.S.
> A.M.A.
> T.X.S., A.1.
> T.X.S.
> M.B.

All the ingots were found on being worked to be quite sound and free from blowholes.

Tests carried out.—The materials were tested—

> (*a*) In tension to destruction.
> (*b*) In compression.
> (*c*) For hardness.
> (*d*) In bending to destruction.
> (*e*) By impact.
> (*f*) Micrographically.

TENSILE TESTS.

The specimens were turned round, and were of ¼ square inch cross section.

The material proved in each case to be brittle, showing a fine grained fracture like cast iron, with no measurable elongation.

The following ultimate tensile stresses were measured :—

TABLE I.

Specimen.	Stress. Tons per Sq. In.	Mean Stress.
F.D.S., 1	4·60	5·00
F.D.S., 2	5·40	...
A.M.A., 1	5·98	5·86
A.M.A., 2	5·74	...
T.X.S., A.1, 1 . . .	5·60	5·64
T.X.S., A.1, 2 . . .	5·68	...
T.X.S., 1	5·28	5·32
T.X.S., 2	5·36	...
M.B., 1	4·64	4·34
M.B., 2	4·04	...

COMPRESSION TESTS.

The ingots were planed up in 1 inch cubes, and the length, breadth, and height of each cube were measured accurately with micrometers. Each cube was loaded up 1 ton at a time, and after each ton the specimen was taken out, and the length, breadth, and height were again measured accurately. Tests were also made to see whether any difference occurred when the material was tested in one direction of the ingot or in a plane at right angles to it, but apparently there was no alteration in the effect. The method of procedure during the tests entailed a very large number of measurements, and on the twenty-four cubes tested, about 1610 measurements were taken. By taking such a large number of observations the behaviour of the specimen

throughout the whole test could be observed, and stress-strain curves were drawn out for each cube.
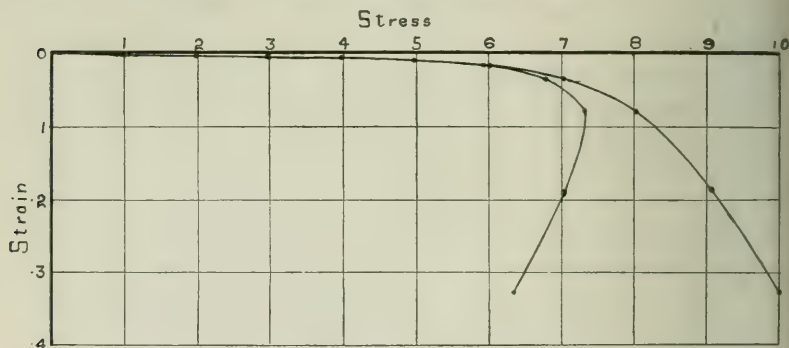
FIG. 1.—Actual and Nominal Stress Strain Curve.

In nearly every case the specimen began to give way gradually at a stress of between 5 and 7 tons. Curves Figs. 1 and 2 show this clearly. At this point the time
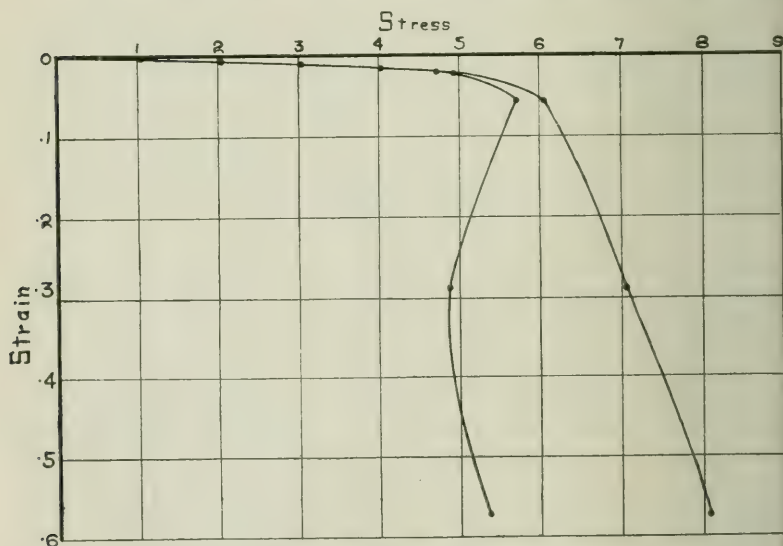
FIG. 2.—Actual and Nominal Stress Strain Curve.

effect was so noticeable that it was further investigated. Soon after the specimen began to yield, "shear" lines

appeared along the sides of the cube at angles of 45°, and later on large vertical cracks also appeared. When these cracks appeared the volume increased.

It was practically impossible to measure either the yield point or the breaking load of these alloys, because neither is clearly defined. Signs of fracture began to appear in the F.D.S. specimens at a stress of about 9 tons, and in the M.B. specimens at a little less than 6 tons stress. In all of the specimens the yield point seemed to be near to these same stresses; there was no definite fracture. As will be seen later, some of the cubes carried a load of 50 tons, which simply flattened them out.

A large number of preliminary compression tests were made. Various shapes were tried, and in all some fifty specimens were tested. Finally, it was decided to use the inch cubes, and careful note was made of the time during which the load was allowed to remain on the material. The results show the average strain (per cent.) for a 6-ton load—approximately 6 tons stress—obtained as a mean of tests on four specimens. The real comparison, therefore, of the behaviour of the metals is the average strain. The 6-ton load was on the specimens for fifteen minutes; the percentage strain was obtained by micrometer measurements. Sensitive extensometers were considered unsuitable for commercial work. It will be seen that these comparative figures vary much more than those obtained by other tests.

There would have been the same relative order, but far less variation, if some lower load, say 2 tons, had been selected. Unfortunately, with the harder materials, the distortion at such a load is so small that comparative figures would be difficult to obtain. While every endeavour was made to ensure the best conditions of loading, neither the plates of the machine nor the sides of the cube were parallel within a thousandth part of an inch.

Therefore it would seem that the strain column gives us a rough, but by no means rigid, method of comparison of the materials. It is, indeed, noticeable that compression tests are not very satisfactory except for a very brittle material, such as cast iron. It would appear to be more satisfactory to make

hardness tests to obtain more rigid values of the relative properties of the materials for carrying compression loads.

The results of the compression tests are as follows :—

<center>TABLE II.</center>

Specimen.					Mean Stress. Tons per sq. In. at 6-Ton Load.	Average Strain.
					Per Cent.	Per Cent.
F.D.S.	.	.	.	.	5·98	1·45
A.M.A.	.	.	.	.	5·95	0·66
T.X.S., A.1	.	.	.	.	5·88	3·12
T.X.S.	.	.	.	.	5·98	4·07
M.B.	.	.	.	.	5·84	30·63

Time Effect in Compression Tests.—One very remarkable characteristic of all these white metals, was that there was a very large time effect at loads of about 8 or 9 tons. The metal began to yield, this yielding continuing for some time. The beam of the testing machine could be seen dropping.

When this was first noticed, it was considered very desirable to determine exactly the effect that time had on the material under stress. When a load of 9 tons was employed the time was taken, and the distance between the two steel plates between which the metal was compressed was measured every two or three minutes by means of sliding callipers. These measurements were taken until the contraction in the specimen during the time between two consecutive readings grew very small. The duration of time over which these measurements were taken was twenty or thirty minutes, and in this time one specimen contracted as much as 0·4 inch. or 48 per cent., of depth of cube at commencement of time test.

Time-strain curves were drawn from these results; an example of one is given in Fig. 3. It will be seen that the rate of contraction of the specimen becomes less and less as the time increased.

In the hardness tests also the effect of time was notice-

able, and it is considered that in such tests the time during which the load is applied should be specified.
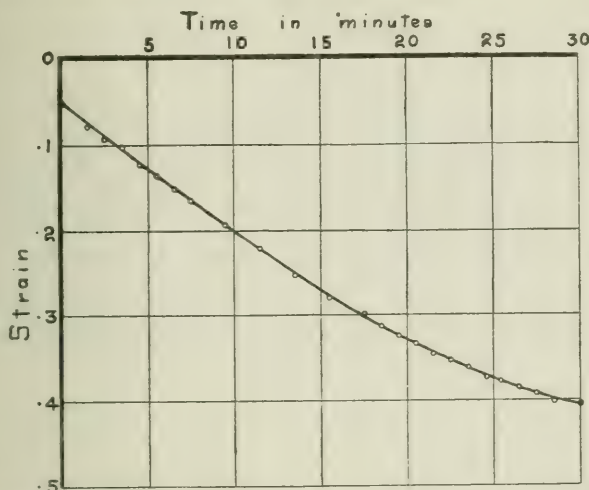
FIG. 3.—Strain-time Curve obtained during Compression Test at 9 Tons.

HARDNESS TESTS.

It is noticeable that in this country the study of the relative hardness of the materials used in engineering construction has been somewhat neglected. In consequence, our standards of hardness are determined from the Continental units of length, &c. The method employed in ascertaining the comparative hardness of these varieties of bearing metal is that known as "Brinell's." It consists of pressing, under a certain load, a hard steel ball into the polished surface of the specimen. The diameter of the impression made by the ball is then measured accurately; in these tests this was done by means of a microscope. Brinell's "hardness number" is given as equal to—

$$\frac{\text{Load (in kilograms)}}{\text{Area of curved surface (sq. mm.)}}$$

$$= \frac{P}{2\pi r\left(r - \sqrt{r^2 - \frac{D^2}{4}}\right)}$$

where

P is load on ball in kilograms,
r is radius of ball in millimetres,
D is diameter of impression in millimetres.

As the "hardness number" given by Brinell's * method varies slightly with the diameter of ball and the amount of the load, he specified that a ball 10 millimetres in diameter and a load of 500 kilograms should be used. In these tests a ball of diameter $\frac{3}{8}$ inch = 9·525 millimetres and a load of 0·5 ton = 508 kilograms were employed. A close approximation to Brinell's conditions was thus obtained.

On each specimen of material five or more hardness tests were made under different conditions. The load was allowed to remain on for 1 minute at 0·2 ton, 0·5 ton, and 1·0 ton. The load of 1 ton was also allowed to remain on for 5 minutes and for 20 minutes. The effect of the time on the behaviour of the material under load was thus shown. The "hardness numbers" obtained for the different varieties with a load of 0·5 ton for 1 minute were as follows:—

F.D.S., 30·8 ; A.M.A., 30·1 ; T.X.S., A.1., 22·3 ; T.X.S., 20·5 ; M.B., 17·2.

Bending Tests.

The specimens were rectangular beams $\frac{3}{4}$ inch deep by about $1\frac{5}{16}$ inch wide. They were supported at points 10 inches apart, and were loaded centrally.

The skin stress at fracture was determined. Also the permanent dip of the beams at fracture was recorded, and this enabled a comparison to be made of the distortion which the materials could bear.

Table III.

Specimen.	Width. Ins.	Depth. Ins.	Load. Lbs.	Maximum Stress. Tons per Sq. In.	Maximum Deflection. Ins.
F.D.S.	$1\frac{5}{16}$	$\frac{3}{4}$	950	8·60	0·33
A.M.A.	$1\frac{5}{16}$	$\frac{3}{4}$	935	8·48	0·29
T.X.S., A.1	$1\frac{5}{16}$	$\frac{3}{4}$	875	7·93	0·50
T.X.S.	$1\frac{3}{8}$	$\frac{3}{4}$	825	7·13	0·57
M.B.	$1\frac{5}{16}$	$\frac{3}{4}$	700	6·34	0·68

* Wahlberg, *Journal of the Iron and Steel Institute*, 1901, No. I. p. 243.

It will be noticed that M.B. yielded more than twice as much as F.D.S. or A.M.A.

Impact Tests.

Rectangular specimens were used, about 1 inch wide, $\frac{1}{4}$ inch thick. They had notches on each side about $\frac{1}{16}$ inch deep. The specimens were firmly gripped in a vice at the level of the notches, and fractured by a pendulum bob. The energy of the ball was observed before and after hitting the specimen. Hence the energy in foot-pounds per square inch of section sheared was calculated.

Table IV.

		Energy per Sq. In.	Mean.
F.D.S., 1 .	. . . . .	2·94	
,, 2 .	. . . . .	2·74	
,, 3 .	. . . . .	3·10	
,, 4 .	. . . . .	2·94	2·987
,, 5 .	. . . . .	3·18	
,, 6 .	. . . . .	3·02	
A.M.A., 1	. . . . .	2·96	
,, 2	. . . . .	3·33	
,, 3	. . . . .	3·84	
,, 4	. . . . .	3·09	3·48
,, 5	. . . . .	3·80	
,, 6	. . . . .	3·81	
T.X.S., A.1, 1 .	. . . .	2·22	
,, 2 .	. . . .	2·41	
,, 3 .	. . . .	2·16	
,, 4 .	. . . .	2·26	2·417
,, 5 .	. . . .	2·70	
,, 6 .	. . . .	2·75	
T.X.S., 1 .	. . . . .	1·96	
,, 2 .	. . . . .	1·73	
,, 3 .	. . . . .	1·83	
,, 4 .	. . . . .	1·98	1·892
,, 5 .	. . . . .	1·88	
,, 6 .	. . . . .	1·97	
M.B., 1 .	. . . . .	1·82	
,, 2 .	. . . . .	2·01	
,, 3 .	. . . . .	1·78	
,, 4 .	. . . . .	2·22	1·945
,, 5 .	. . . . .	1·87	
,, 6 .	. . . . .	1·97	

SUMMARY OF RESULTS.

TABLE V.

Material.	Compression.		Tension. Stress in Tons per Sq. In. at Fracture.	Brinell's Hardness Number. Load 508 Kgs.	Bending.		Impact. Energy used per Sq. In. Foot-lbs.
	Stress. Tons per Sq. In.	Strain. Per Cent.			Stress. Tons per Sq. In.	Distortion. In.	
F.D.S. . .	5·978	1·45	5·00	30·8	8·60	0·33	2·99
A.M.A. .	5·943	0·66	5·86	30·1	8·48	0·29	3·48
T.X.S., A.1	5·878	3·12	5·64	22·3	7·93	0·50	2·42
T.X.S. . .	5·982	4·07	5·32	20·5	7·13	0·57	1·89
M.B. . .	5·839	30·63	4·34	17·2	6·34	0·68	1·94

A study of the above table reveals the fact that there seems to be very little difference between the metals F.D.S. and A.M.A., so far as the physical characteristics are concerned. In some of the tests the A.M.A. metal is superior to F.D.S. It was practically impossible to measure the breaking loads of these metals in the compression tests. The elongations are not recorded for the tension tests, as they were too small to be measured accurately with ordinary workshop appliances.

There was very much less distortion when the compression load remained on the metals for a short interval of time, say one minute. All of these metals would carry considerably higher loads for a few seconds. The fifteen minutes compression test may be considered as a severe trial of the metals.

The material M.B. was the only one which was very much distorted after carrying for fifteen minutes a load of 6 tons. This is explained by the fact of it being the alloy containing the highest percentage of lead. It is really on the border line between tin basis alloys and lead basis alloys. It may here be remarked, however, that even the M.B. satisfactorily withstood loads and stresses far in excess of any that would be used by designers of bearings for practical work; while the other alloys showed a very large margin of safety.

PLATE IV
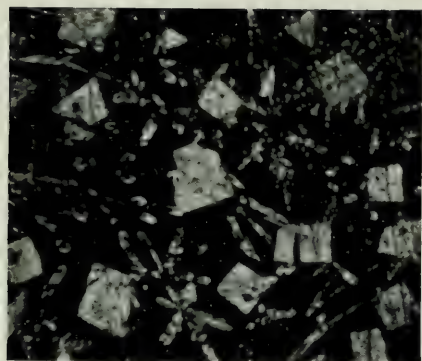
FIG. 1.
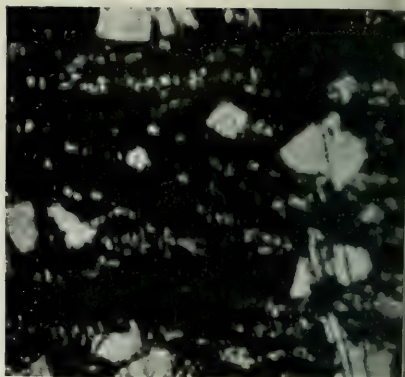
FIG. 2.
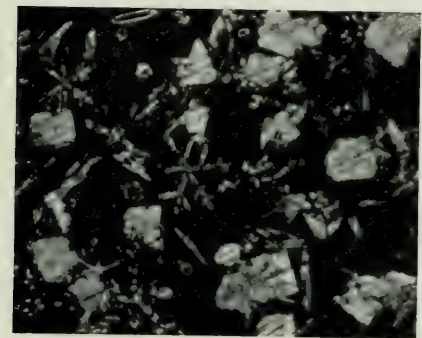
FIG. 3.
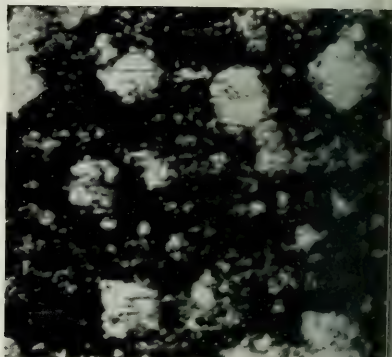
FIG. 4.
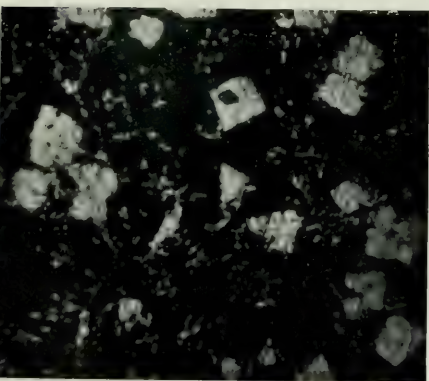
FIG. 5.
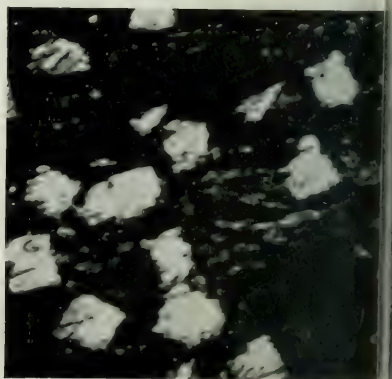
FIG. 6.

Microscopical Examination.

For the microscopic examination specimens were obtained from the test-bars before applying any tests, and also from the specimens after being subjected to compression. These specimens were polished in the usual manner on Hubert's French emery paper Nos. 0, 00, 000, and 0000 successively, the final polishing being effected on chamois leather with Globe polish. The polished surface was then etched with concentrated hydrochloric acid, and examined on a Zeiss apparatus at a magnification of 100 diameters.

The specimens taken from the test-pieces after subjection to compressive stresses of about 6 tons, given in Table II., showed so little disturbance of the original structure, that it was deemed desirable to secure further specimens from test-pieces which had been subjected to a compressive stress of 50 tons. From a number of photographs obtained, a few only have been selected to indicate the general type of structure of these alloys and the effect of the compression on same. (See Plate IV.)

Fig. 1 shows the structure of the original F.D.S. alloy, in which will be observed distinct cubes of SnSb, and star-shaped crystals of $SnCu_3$ in a ground mass consisting mostly of solid solution.*

Fig. 2 shows the same specimen after compression under 20 tons, in which it will be seen that the SnSb crystals have well maintained their shape, whereas the star-shaped crystals have been flattened out by the flow of the softer matrix.

Figs. 3 and 4 show the original and compressed structure of specimen A.M.A., and Figs. 5 and 6 the same of specimen T.X.S., A.1.

Owing to the limitations of space, it has been impossible to include a larger range of photographs.

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* For the part played by these crystals in the utility of bearing metals, see Law's "Alloys."

Conclusions.

The above results show the physical characteristics of the various materials, and it is for the members to discuss their relative importance. It is very much less difficult to make such tests than to run friction tests, and it would appear, therefore, to be an advantage if some definite decision could be come to concerning the most suitable physical tests for such metals.

The results of the microscopic examination show distinctly that the SnSb crystals are not materially affected under very considerable pressure. The $SnCu_3$ crystals, although materially deflected by the flow, evidently must exert a considerable influence in strengthening the structure.

The authors wish to express their thanks to the authorities of the East London College for the facilities afforded for the tests; to Messrs. H. L. Morgan and I. D. Sky, senior students of the College, who assisted greatly in the tests and the preparation of apparatus; and to Mr. C. O. Bannister, A.R.S.M., for assistance and advice in connection with the preparation of the photomicrographs.

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DISCUSSION.

Mr. W. E. WATSON (London) said that, as managing director of the firm which made the specimens referred to in the paper, he desired to remark on two points—

1. He quoted page 195 of the paper, which said, " It will be seen from the results given that in some of the tests the most expensive alloy, that containing no lead, does not show the best results," and quoted his experience of shipbuilders having found his company's lead-basis metals perfectly satisfactory for tunnel bearings, this being to his mind a practical confirmation of the scientific points arrived at.   He also quoted his experience of a ship at sea, bearing out above points. He, however, did not suggest lead-basis alloys for eccentric straps, main bearings, or heavier bearing parts, but only for tunnel bearings, where his company's alloys had given perfect satisfaction.

2. The second point made was that he found, as a supplier of anti-friction metal to the general public, a feeling abroad that there was a certain amount of magic about making such material, and there was a certain class of engineers who would never make investigations, but just used the same they had always employed before.   He did not say all engineers took this line, but a great many did.   He contended that if engineers of the class just mentioned would take a little time to consider the deliberations and investigations of the Institute of Metals, they would no doubt be able to effect an economy in the actual cost of metals, and they would very probably be able to get metals of a better class than those which had been supplied by makers of well-known names, whose products they used without further investigation.

COMMUNICATIONS.

Mr. C. O. BANNISTER, Assoc.R.S.M. (London), wrote that, in view of the very small amount of published information on the properties of commercial white-bearing metals, the paper by Professor Smith and Mr. Humphries should be of distinct service.   It was unfortunate that the conditions of the white-metal industry were such as to render it inadvisable to publish full particulars of the chemical composition of these alloys, and it was to be hoped that, in the near future, such information would be as accessible as was that regarding the composition of ordinary and special steels.   As the paper stood, there was no means of making a comparison of the relative values of the alloys, and, if the authors could indicate this in some way, such as by giving the cost per ton, using as a basis the F.D.S. alloy at say, 100, then the value of the paper would be decidedly increased.   As to the mechanical tests carried out, it was remarkable that the tensile tests should be so similar with materials differing so much in composition, and that the strain under

compression should vary so widely. There was little doubt that, of the tests given, the hardness test and the compression test were the most useful. The compression test, followed by microscopic examination, should prove very valuable, and the results obtained and illustrated in the paper were most interesting. During the preparation of specimens for microscopic examination, much information might be obtained by noting the behaviour of the material under the action of the saw and file.

Mr. WESLEY LAMBERT (Woolwich) wrote that the chief object of the paper, viz. to promote a discussion upon the tests to be applied to ascertain the suitability of white anti-friction bearing metals, which *practical* men think are the most suitable, was a praiseworthy object.

That the paper was not fully discussed at the Institute Meeting, was probably due to the fact that the users of bearing metals would more probably be found in the ranks of the members of the Institution of Mechanical Engineers and its kindred societies.

Personally, the writer was of opinion that neither tensile, bending, or impact tests were necessary.

He owned to a certain amount of trepidation in suggesting that the best application of the following tests should be considered :—

1. *Degree of Hardness.*—(*a*) Resistance to abrasion ; (*b*) resistance to penetration ; (*c*) behaviour under varying static loads.

2. *Melting.*—(*a*) Melting-point ; (*b*) amount of scum ; (*c*) tailing ; (*d*) fluidity ; (*e*) liquation on recasting.

3. *Specific Heat.*

4. *Corrosion by Fatty Acids.*—(*a*) When exposed to atmospheric influences and varying temperatures ; (*b*) repeated, but in contact with other metals.

Mr. E. F. LAW, Assoc.R.S.M. (London), wrote that the authors had very wisely defined the limits of their paper and its purpose, and any discussion on the paper must be confined within those limits. Briefly stated, the purpose of the paper was to promote a discussion, with the object of determining, if possible, whether some simple physical test might be used in place of the elaborate friction tests usually employed to test the properties of an anti-friction alloy.

The answer to the question must depend largely on the point of view. If, for example, a new and untried alloy of unusual composition was to be investigated, the answer must be in the negative ; but if, as was more commonly the case, the object in view was the examination of a standard alloy in order to test its suitability for service, the question was greatly simplified. A well-known American authority had declared that, in the case of yellow-metal bearings, a tensile test was sufficient for most purposes, but this cannot be claimed for the white-metal alloys. Of the tests described by the authors, there was no doubt that the microscopical examination was the most important, and probably the only really useful one, as it was capable of revealing the usual defects which gave rise to undue heating. Those defects (apart, of course, from

faults in lubrication) were: (1) Incorrect composition : (2) Segregation ; (3) Presence of oxides or dross ; (4) Incorrect casting temperature.

While the first of these was readily settled by chemical analysis, the others were immediately detected by a microscopical examination. Moreover, in the hands of an experienced worker, the very process of polishing gave a very fair indication of the way in which the alloy would behave in service. For the ordinary purposes of testing, therefore, chemical analysis and microscopical examination were sufficient, but for research work more elaborate friction-tests must be relied upon. The authors had certainly rendered a service in bringing forward a subject which was of such practical importance.

Professor T. TURNER, M.Sc., Honorary Treasurer, wrote that the subject of tests of bearing metals was an important one, as some alloys were so much more costly to produce than others, and they varied so much in their endurance under differing conditions. The real question raised in the paper under discussion was as to whether tests should be adopted which approximated to actual working conditions, or whether an attempt should be made to record certain definite physical properties of the alloys. Something might be urged on both sides, and even a combination of methods of testing might be advocated. From the scientific point of view he was inclined to think that the plan adopted by the authors was correct, though the advantage of tensile tests in this case might be questioned. Hardness tests appeared to be specially valuable, and crushing or transverse tests might also be used. Something else was, however, wanted to indicate the relative wear under certain loads, and at given speeds, though such tests presented some difficulties. It would probably be better for the manufacturer, in the end, to know that alloys which had certain compositions, and certain physical properties, gave particular results in practice, than to work on merely qualitative knowledge or general experience. If physical properties could be correlated with composition on the one side, and with results in practice on the other, makers should be able more accurately, and often more cheaply, to produce the exact material which might be required for a particular purpose.

Mr. A. G. WARREN, B.Sc. (East London College), wrote that in conducting mechanical tests, of such varying natures as those made by the authors, many difficulties were presented. In the first place, the materials were apparently ductile when tested in compression, and brittle when tested in tension. It would have been interesting to have seen the results of extensometric tests of tension test-pieces under loads, less than the breaking loads (as recorded), and which were allowed to act for a considerable time. The writer was inclined to think that a measurable extension might have resulted, and that lengthy tests would have revealed some evidence of plasticity. The " time effect," in such testing, was a factor which was often under-estimated. That was evident even in routine work upon steel. Different observers would obtain, for themselves, perfectly consistent results for the fracturing load of a material :

O

yet considerable variations would exist between the readings of the several experimenters. The discrepancies could only be accounted for by the different rates of loading.

Many points were raised by the summary of the results obtained by the authors (Table V.). M.B. was weak in tension and plastic in compression and bending. Weakness and plasticity, when combined, gave a low hardness number. Under an impact test, the material was, however, as strong as T.X.S., although the metal fractured in tension. That was accounted for by the fact that the *work* required to fracture a material involved two factors—force and distance. The *plasticity* of M.B. enhanced its impact figure.

Further, such materials, tested as beams, fractured in tension. That appeared to be contradicted by the fact that the stress recorded under "Bending" was some 40 per cent. to 50 per cent. higher than that recorded under "Tension." The bending stresses were, however, worked out on the assumption that the stress was proportional to the distance from the neutral axis—an assumption which was more convenient (for the purposes of comparison) than justifiable.

It would be noted that the figures for the distortion, during bending, though varying less, were in the same order as those for the strain under compression.

The Authors wrote, in reply, that Mr. Watson's remarks concerning his practical experience of lead basis alloys were of interest, and there seemed to be no reason why tunnel bearings should not be lined with such metal.

It was the experience of the authors that many engineers thought such bearing metals were obtained by secret process. To a certain extent that might be a correct view, but on the other hand it was a fact that there had been too little scientific investigation on this subject. Undoubtedly large sums of money were wasted by shipbuilding and other firms because they would not investigate the matter, but, having once adopted a particular brand of alloy, would not alter or try any other kind.

Mr. C. O. Bannister's suggestion as to a means of making a comparison of the relative value of the alloys was a good one, and taking the value of the F.D.S. alloy as 100, the value of the other four alloys would be as follows :—

							Per Cent.
F.D.S. .	.	.	.	.	.	.	100
A.M.A.	.	.	.	.	.	.	92
T.XS., A.1.	.	.	.	.	.	.	80
T.X.S. .	.	.	.	.	.	.	75
M.B. .	.	.	.	.	.	.	52

Mr. Wesley Lambert seemed to suggest that the members of the Institute of Metals were not interested in physical tests. In the opinion of the authors it was most important that such tests should be made and recorded. The great reliability and uniformity of mild steels was due, in no small measure, to the numerous published tests on steels. The tensile, bending, and impact tests were included, as they confirmed the other

physical tests. It was not easy to see how the resistance to abrasion tests could be quantitatively carried out. Resistance to penetration gave the hardness number; behaviour under varying static loads was shown by the compression tests. The corrosion tests seemed worthy of investigation, and might possibly be taken up by the Corrosion Committee.

Mr. Law put forward the suggestion that friction tests were required for further progress. Such work was difficult unless done under research conditions. The unsatisfactory part of microscopic tests was that there was no certainty of the material being uniform. Only quite a minute portion could be so examined. The experience of steelmakers was that microscopic testing was a very good addition to other tests.

Professor Turner's confirmation of the manner in which the problem had been approached was gratifying. The advantage of quantitative results obtained in a college laboratory was that they could be tested and repeated. Results in practice were obtained under such varying conditions that it was very difficult to repeat them. That was the whole object of physical tests.

Mr. Warren's remarks concerning extensometric tests showed that he did not fully appreciate the danger to the instrument used for measuring extensions when a brittle material was tested. The authors' experience on " time effect " confirmed Mr. Warren's statement. That the materials gave results in the same order for all tests was a remarkable demonstration of the uniformity of the material. That was a great feature of the experiments. Although some hundreds of specimens had been tested there was practically no variation in records of different specimens of the same composition, manufactured at different times. That fact alone proved that many of the difficulties of manufacture had been overcome, and that a reliable material was being made daily for bearing purposes.

THE ADHESION OF ELECTRO-DEPOSITED SILVER IN RELATION TO THE NATURE OF THE GERMAN SILVER BASIS METAL.*

By ANDREW McWILLIAM, A.R.S.M., M.Met., and W. R. BARCLAY, A.M.I.E.E.

(Respectively Assistant-Professor of Metallurgy and Lecturer in Electro-Metallurgy in the University of Sheffield).

INTRODUCTION.

A few years ago the authors had their attention specially drawn to a rather serious trouble in connection with the behaviour of high-quality electro-plated spoons and forks under very severe conditions of wear. It is well known that at the present day a much larger proportion of such goods made are used in hotels, in steamboats, and by caterers than formerly. Owing chiefly to the necessities of the case, but partly to the destructive instincts of virile humanity, these goods are subject to very much severer trials than they would have undergone had they found their way into use in the service of private families, for in hotels, spoons and forks may have to be gathered up into large baskets and thrown into the receptacle in which they are to be washed, a kind of treatment that must be remembered in considering what follows.

A large quantity of spoons and forks, manufactured presumably under the best commercial conditions, examined and passed by experienced observers before being sent out from the factory, and apparently only differing from ordinary products in having an exceptionally heavy deposit of silver, were, after actual usage for eighteen months or so, returned to the makers with the complaint that the deposited silver coating was "peeling" or "stripping" along the edges and from parts of the surfaces of the articles.

Figs. 1 and 2 (Plate V.) will give an idea of the way in which this occurs.

As the trouble was not confined to a few isolated pieces,

PLATE V

FIG. 1.—Fork, showing the stripping of the Silver Coating.

FIG. 2.—Fork, showing stripping beginning at the edges.

but extended to the majority of the articles in a consignment, and was also in time found to occur in connection with goods from different firms, it was felt that the matter warranted a thorough investigation, particularly as no specific fault could be traced in any of the processes through which these goods had passed, where the details of the processes could be known. A full inquiry into the causes of this fault was made by request, and since the first part of the investigation was finished, quite a number of similar cases have been brought to the notice of the authors from independent sources and by personal observation. Thinking, then, that the subject was one of vital importance to electro-plate manufacturers, as well as of great interest in connection with the non-ferrous trades, with the concurrence of the gentleman who first asked for the investigation to be made, the authors determined to place the results of their experiences before the members of the Institute of Metals, supported as they are by further experiments recently carried out.

In order to correct a misapprehension which might arise, it may be necessary to point out that no attempt is here made to discuss the ordinary causes of the " stripping " or " peeling " or " blistering " (as it is sometimes called) of electro-deposited silver from the basis metal during processes of manufacture, such, for instance, as that due to inefficient cleansing from grease or from oxide, careless treatment in scratch-brushing, or in the general preparatory stages of treatment, unsuitable plating liquid, &c., because articles so treated rarely pass from the hands of reputable manufacturers, the faults being revealed during the subsequent finishing and burnishing processes, it being well known that if the slightest trace of grease or oxide remain on the surface of the basis metal, the electro-deposited silver will blister under the pressure of the steel burnishing tools used in finishing.

The investigations were conducted from an entirely different point of view, the authors being convinced that the stripping of silver from articles which had passed all the ordinary tests of the manufacturer, and had indeed been in the hands of the users for periods varying from six months to two years, could hardly be ascribed to any of the ordinary causes mentioned.

From general experience, and from the examination of many plated articles that had been a generation in wear, the authors had formed the opinion that the adhesion had something to do with the nature of the basis metal, hence the investigations described in the present paper were undertaken with the view of determining not only the nature of the adhesion of electro-deposited silver to the alloys known commercially as German silver or nickel silver as a basis metal, but also to find out what difference, if any, exists between the various grades of German silver in general use in the trade, as to their suitability to form a basis metal for heavily electro-plated articles which are liable to receive rough usage.

These investigations are described under the following heads :—(*a*) Samples tested, (*b*) Tests applied, (*c*) Results of tests, (*d*) Conclusions.

(*A*) Samples Tested.

The earlier experiments were made on a number of spoons and forks of various sizes supplied by manufacturers, and of the grades known in trade circles as Firsts, Seconds, Thirds, and Fifths. Analyses of these were not made, but the makers reported them as having approximately the following compositions as to nickel: Firsts, 20 per cent.; Seconds, 16 per cent.; Thirds, 12 per cent.; Fifths, 7 per cent. The content of copper appeared to vary between 56 and 59 per cent., according to the few assays made. In addition to these spoons and forks, several test strips were obtained of each of the grades described, and of a similar character to spoon and fork blanks. All the pieces were treated so far as possible in exactly the same manner, and cleaned, prepared, and electro-silver-plated, according to the best methods in general use, with the one exception that a few of the samples were given a preliminary coating of copper before silver-plating. The silver deposits given to these were equal to the highest qualities for high-class work, and the electro-plating was done by experienced workers, under the ordinary conditions of works practice. The experiments on the above pieces were carried out several years ago, and samples were electro-plated

in different works.   Those which will now be described have been made under the personal supervision of the authors during the last twelve months, as, in order further to test the matter, in view of the possible publication of results, they determined to prepare a series of nickel silver alloys corresponding approximately to those in ordinary use amongst electro-plate manufacturers.

The following table gives the compositions of the alloys accordingly made :—

TABLE I.

Marks.					Nickel.	Copper.	Zinc.
					Per Cent.	Per Cent.	Per Cent.
A	.	.	.	.	20	57	23
B	.	.	.	.	18	57	25
C	.	.	.	.	16	57	27
D	.	.	.	.	14	57	29
E	.	.	.	.	12	57	31
F	.	.	.	.	10	57	33
G	.	.	.	.	8	57	35
BZ	.	.	.	.	18	50	32
BC	.	.	.	.	18	64	18

The choice of the above alloys is largely empirical, but they are fairly representative of the usual grades of copper-zinc-nickel alloys in commercial use.   An endeavour has been made to systematise the series by fixing the proportion of copper on the uniform basis of 57 per cent. throughout, with the exception of the last two members, BZ, in which 7 per cent. of the copper is replaced by zinc, and BC, in which 7 per cent. of zinc is replaced by copper.

As the authors have the work well in hand for a paper on some of the properties of this series of alloys, no attempt is here made to discuss this aspect of the subject, but the whole series has already proved a remarkably successful one with regard to desirable working properties.

Each alloy has been made under the ordinary conditions of works practice, manganese being used as a deoxidising agent. The metal was cast into ingots of about 18 lbs. weight.   These were rolled into sheets of a thickness and width suitable for

spoon and fork blanks, and cut up into strips each 8 inches long and varying from $\frac{1}{2}$ to 1 inch in width.

In every respect these strips correspond to spoons or forks with the exception that they have not undergone the process of stamping. A few odd strips from some members of the series have been made into forks, and these have been submitted to tests in the same way as the blank strips.

The electro-silver-plating of these strips has been done under the best commercial conditions of manufacture, in an electroplating shop through which large quantities of spoons and forks are daily passing. They have been prepared for the depositing vat with due care and with all the precautions which would be taken by any careful electro-plater to ensure the best adhesion of the silver deposit, but they were not subjected to exceptional treatment.

The electro-plating solution used was the usual standard one of the double cyanide of silver and potassium, and the weight of silver deposited on each strip was at least equal to that given to the highest qualities of spoons and forks and to those previously described.

Table II. gives the weight of deposit on the strips of each alloy, calculated per square inch of the surface.

TABLE II.

Marks	Deposit per Square Inch in Ounces Troy.
A	0·0196
B	0·016
C	0·0215
D	0·021
E	0·017
F	0·024
G	0·024
BZ	0·0198

The slight variation in the weight of deposit is explained by the fact that it was considered advisable to give each strip a minimum deposit at least of the thickness indicated above, without in any way interrupting the course of deposition, such as by taking the specimens out of the vat for intermediate scratch-brushing, a practice often followed in the making of very heavy deposits in order to keep the coating as smooth as possible.

The strips were consequently in the vat during the greater part of the working day, and naturally the rate of deposition varied as more or less work passed through the vat in the course of the day's operations.

(*B*) Tests Applied.

The guiding principle in designing tests for the purposes of the investigation was to subject the samples to strains such that the basis metal and its silver coating would be given, if possible, a certain amount of movement relative to one another, and in addition that the coating itself should be fractured. In all the cases of stripping of which mention has been made in the Introduction, the stages of development of the fault have appeared to be, first, that along the edges of the spoons or forks concerned the silver deposit has in course of severe wear become broken or cut through, then these broken edges have gradually curled or peeled up (see Figs. 1 and 2, Plate I.), and if the deposited silver is thick, and therefore of sufficient substance, it may readily be pulled away from the basis metal surfaces. In some cases it has been possible by care and patience to peel the silver coating away from a fork almost from one end to the other.

With these points in view several preliminary tests were made with the apparatus available, and finally it was decided to adopt the test which had first appealed to the authors, namely, a simple cold bending test. One part of the sample is gripped in a vice and the free part is bent to and fro until it breaks off. It is advisable that the angle of the bend should be about a right angle, in order to ensure that the deposit and the basis metal get sufficient movement relative to one another. It will be evident that this test is an extremely severe one, and that unless the metals are holding together almost as one, the silver must be parted from its base, for the silver on the outside of the bend must move a greater distance than the basis metal, and on the inside of the return bend a less distance.

In view of the results it should be noted also that the order of increasing ductility of the metals being as a rule from the high percentage nickel alloys to the low ones,

the latter bearing more bending before fracture than the former, the test is more severe for metals of the G, F, and E types than for A and B.   In practically every case the samples were tested to destruction.

Microscopical Examination.—In addition to the mechanical tests applied, representative sections were cut from each series for microscopical examination.

(*C*) Results of the Tests.

In the case of all the samples of the Third and Fifth grades and of the G, F, and E specimens of the special alloys in Table I., it has been exceedingly difficult to peel up the silver coating in any way.   In some few cases just at the point of fracture it has been possible to raise the silver coating very slightly at the top, but in endeavouring to strip it further the silver, though very tenacious and ductile, has broken rather than leave its base.   It has indeed repeatedly surprised the authors to find how extremely adherent the coating is even under the severest tests.   Test-pieces of first and second grades and of A and B of Table I., however, behaved in a very different manner.   In practically every instance the silver coating left the base at the point of fracture, and in a large majority of instances it could be pulled away quite readily from a considerable part of the surface without breaking the silver.

In the cases of C and D evidence of imperfect adhesion was not so pronounced as in A and B, still the authors do not regard these as so good as E, F, and G.

In the earlier experiments described, a few samples of first and second grades were given rather a different treatment; they were prepared for plating in the ordinary manner, but before silver was deposited on them they were given a thin coating of copper from an alkaline copper solution, then transferred to the silver vat and given a heavy deposit of silver.   These samples were then put through the same tests as the previous ones, and again there was obtained evidence of imperfect adhesion, though not quite to the same extent as formerly.   The adhesion even in these cases was

not to be compared, however, with that obtained with the lower percentage nickel alloys G, F, and E.

The electro-deposited silver in all the cases was tough and strong.

In order to carry the matter still further the authors quite recently obtained from another firm of German silver manufacturers a few spoons and forks of first and second grades, and the results given by these pieces when plated and tested are in every way confirmatory of the foregoing results.

A considerable number of test-pieces after plating and before being submitted to the bending tests were burnished by experienced silver finishers. This process is considered in the trade to be, in addition to a help in finishing, a reliable means of testing the adhesion of the silver. The operation is usually done by clamping the article firmly on a bench and then passing a smooth dry steel burnishing tool over the entire surface and particularly on the edges. Unless the silver is in closest contact with its base at every point, the deposit will not pass this test without blistering. Every one of the test-pieces—spoons, forks, and blank strips— used in the investigation emerged successfully from this test.

Small divergencies in results were noticed between test-pieces made from nickel silver that had been deoxidised and those made from alloy that had not been deoxidised, the former giving better results than the latter for the same grades of alloys, but the number of the latter used were so few that attention is only drawn tentatively to the result, as the authors intend to make further comparative tests in the future.

Results of Microscopical Examinations.—Samples of every type were carefully examined under the microscope at about 40 and 400 diameters, and in special cases at 1000 diameters. It was found that in every case, when not submitted to strain, the silver deposit appeared closely adherent, and the microscope did not reveal any marked difference between the nature of the junctions of the deposits with the various alloys. Those pieces from which the silver had lifted after being subjected to severe strain showed that the whole of

the silver deposit had left the basis metal, but in the case of the samples of firsts metal coppered before silver-plating, part of the copper had remained adhering to the silver and part to the alloy.

The photomicrograph shown in Fig. 3 (Plate VI.) represents a transverse section of first-grade German silver coppered before silver-plating. The photograph includes a portion of the place where the mark had been struck, and shows the consequent movement of the two metals. The thin deposit of copper between the nickel silver and the silver is clearly discernible as a narrow dark band. This piece shows the three metals in closest contact throughout.

Fig. 4 (Plate VI.) shows, in transverse section, silver deposited on first-grade metal direct. In one place there is a slight indication of parting, evidently caused by the comparatively rough treatment of sawing and filing given during the preparation of the microsections.

Fig. 5 (Plate VII.) shows part of a transverse section of a third-grade metal dessert fork with a heavy deposit of silver. In this specimen, even at the highest powers, the two metals seemed to be in closest contact. The line of demarcation seen in the photograph is due to the difference in colour between the metal and the alloy.

The scratches are more prominent in the photographs than the authors would have liked, but as the sections were quite sufficiently free for the purposes of their own examinations and records, they did not, when these were originally made, think of wasting any more time on them. When, however, it was decided that they should lay the matter before the members of this Institute, they repaired to the box where all the sections were stored together in order to prepare them more perfectly and a strange thing had happened. The four most typical specimens which had been photographed had been left on the plasticene that had been used for temporary mounting purposes, and the sulphur that this useful material evidently contains had strongly attacked the samples during the three years or so they were laid away. Not only had the surfaces of all four sections been much attacked, but the action extended along

Plate VI

Fig. 3.—Photomicrograph of First-grade German Silver Test-piece, Coppered and Silver-plated. Magnified 140 diameters.

Fig. 4.—Photomicrograph of First-grade German Silver Test-piece, Silver-plated. Magnified 140 diameters.

PLATE VII

FIG. 5.—Photomicrograph of Dessert Fork of Third-grade German Silver
with thick deposit.   Magnified 140 diameters.
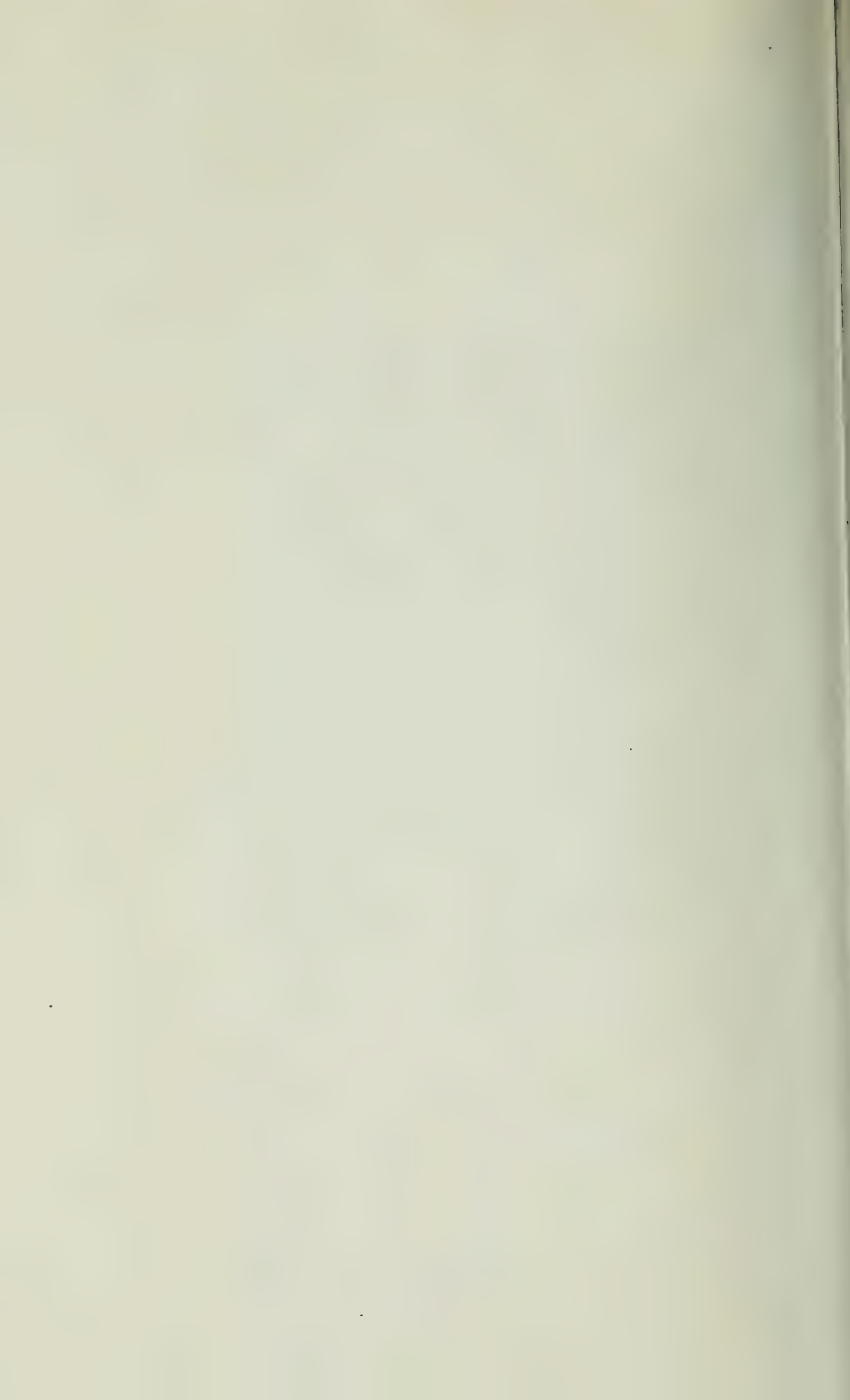
the junctions of the silver with the alloys so that the idea
of re-preparing the samples until they were practically free
from scratches was abandoned. This would really have
been an unprofitable work, for the sections show all that
is necessary. In the case of such a soft metal it is also a
tedious one, for, in contradistinction to a recently published
opinion, the authors find such materials as the comparatively
hard tempered steels much more easy to polish than soft
metals.

(*D*) Conclusions.

The investigations clearly indicate considerable differences
in the adhesion of deposited silver to the various grades
of German silver alloys, even when all are treated under
the same conditions of practice, and the authors are of opinion
that this fact should have full consideration in choosing a
basis metal for articles to receive the thickest silver deposits
given, which will also be required to bear rough usage.
They are not prepared to state dogmatically that any one
particular alloy is best for this purpose, but they consider
they have fully proved that ordinary commercial alloys of
copper, zinc, and nickel containing more than 14 per cent.
of nickel are of doubtful utility in this respect. On the
other hand, alloys of the types of G, F, and E used for
carrying heavy silver coatings electro-deposited with due
care, will endure exceptionally rough usage without giving
any cause of complaint on the ground of the silver stripping.
It should be noted that the tendency to strip increases
with the thickness of the silver deposit. The properties
considered in deciding upon the grade of German silver
to be used as a basis metal for electro-plating are strength,
colour, and malleability. As a general rule, passing from
G to A in the series of alloys the strength increases, the
colour approaches more nearly the white of silver, and the
malleability decreases. With regard to whiteness, however,
where thick coatings of silver are concerned this should
not be considered as a matter of such primary importance
as the perfect adhesion of the silver under the conditions
of wear. Strength is more important than colour, and the

lower members of the series are deficient in strength; but articles having quite sufficient strength and stiffness can be made of the type of alloy recommended by suitable mechanical and heat treatment.

With regard to the nature of the adhesion, the authors do not at present care to advance any theory to account for the differences described, but as they consider that the quicking process forms a superficial amalgam with the basis metal in the first place, and afterwards on the inner surface of the silver deposit, the two amalgams may form a kind of cement between the plating and the basis alloy. It is possible that with the more suitable alloys this very thin film of amalgam is more efficient than with the alloys of higher nickel content. Hence, although the investigations at present in train are undertaken with regard to the general properties and structures of the series of nickel silver alloys given in Table I., it is intended to note specially any changes in microstructure amongst the members of the series, with the view of any possible change in the nature of the amalgam that would be produced. They also, for the same reason, intend, with their new series, to examine, with the highest powers of the microscope, a fresh set of specimens after the most careful preparation. The above idea of the nature of the adhesion is supported by the manner of the tearing of the intermediate film of copper, part of which, as already stated, adhered to the silver and part to the basis metal.

Another possible explanation of the better adhesion might be found in the closer approximation of the mechanical properties of the coating to those of the alloys of lower nickel content compared with those of higher nickel content, or, perhaps, in a combination of these causes, but this aspect requires further experimental investigation.

A strongly worded appeal has reached one of us to support a demand for foundation alloys of higher nickel content to be used for the thickest coatings, which, if carried into effect, as in many other cases of undue interference of the buyer with the practice of the best makers, would defeat its own purpose of obtaining the best article for the required use. It is interesting to note how the metallurgist has to

reconsider the properties of his materials and his methods of manufacture in order to be able to make articles that will do him credit in the world's work when new conditions of life arise requiring these articles to bear a different type of usage. It is no use for him to claim that the usage to which his products are subject is unreasonable, if the new conditions of life require them to bear rougher treatment or some other special strain. He has no say in regard to sociological changes, and if he be wise he will just accept the conditions and endeavour to solve the problem. This was the task placed before the authors, and the practical results of their work have stood the severest trials since their earliest investigations were completed.

The authors have pleasure in acknowledging the kindness of Messrs. W. Gallimore & Sons in rolling their test ingots into sheet.

DISCUSSION.

Mr. T. Vaughan Hughes, Assoc.R.S.M. (Birmingham), asked Professor McWilliam whether in casting the small ingots, especially the higher nickel content alloys, upon which he had experimented, he had experienced any difficulty in producing solid castings. One of the troubles incidental to electro-plating the higher nickel alloys used as a " basis metal " was, to cast them free from blowholes. One cause of the defects referred to in the paper appeared to him to be due to unsound metal. The sample exhibited warranted this assertion. But there were several other causes for the defects described in the paper, none of which could be attributed to the composition of the basis metal. These causes were largely physical and chemical, and were well known to the leading electro-plating firms.

Mr. Arnold Philip (Portsmouth) stated that the Admiralty had a specification for silver plate which was supposed to be quite top-notch, the silver plating being very heavy, and the basis metal containing 19 per cent. of nickel. The paper was very interesting, because during his service in the Admiralty he had never yet come across a complaint of separation of the silver plating from the basis metal. Very stringent tests were carried out on all Admiralty silver plate, both in regard to the amount of silver in the plating, and the composition of the basis metal, and there was no doubt that the goods supplied were quite up to the specification. He would make it his business to inquire whether there was any evidence of the stripping to which the authors had referred. Although there was no doubt, as the authors stated, that electro-plate received rough usage in hotels, in the naval service one would expect the plated articles received probably equally severe treatment.

Mr. T. Mason (Sheffield) said that he thought the paper dealt with a question of very great importance to manufacturers of electro-plate. It had to be borne in mind that Government departments and many mercantile shipping companies provided the formulæ for the basis metal of their electro-plate, and insisted on manufacturers working to that specification, and then, of course, depositing the necessary thick coating of silver upon it. The latter condition was essential, if the appearance, &c., was to be retained for any lengthy period, but it was clear from the paper that some nickel alloys were unsuitable to receive a thick silver deposit, and then wear satisfactorily under the abnormal conditions quoted by the authors. As Professor McWilliam had mentioned, a thin coating of silver, such, for instance, as that required by some auctioneers, would present no difficulty or trouble. He (Mr. Mason) expressed the opinion that that question of suitability of German silver alloys in reference to the great industry of electro-plate manufacture appeared to have been somewhat neglected by technical institutions, and said it was very gratifying to hear the results of some research

work from a scientific standpoint. While he agreed mainly with the conclusions arrived at by the authors, he wished to ask one question on a point which, from his own investigations of a similar trouble, he thought Professor McWilliam and Mr. Barclay might have overlooked. In the paper the authors had suggested that the adhesion was chiefly due to the formulæ of the basis metal used. He wished to ask them whether they had considered the different degrees of adhesion to be obtained by employing varying current densities in the initial stages of deposition. From his own experiments he had found this matter to be a decided factor in the degree of adhesion.

Professor ANDREW McWILLIAM, in reply, said that the point raised by Mr. Mason as to the effect of current density was an excellent one. They had considered varying current density, but had not yet made a systematic series of experiments dealing with the question, although it would be a very good point to investigate. The only difficulty was the carrying of it out in works practice afterwards. With regard to Mr. Vaughan Hughes' question, the metals were cast as ingots, which were worked afterwards by the usual methods. There had been no trouble whatever with blowholes. That might have resulted from the fact that, from experience in the use of nickel in steel, the nickel used in connection with the manufacture of the alloys was thoroughly deoxidised. They were a little chary about mentioning the general question when they remembered that they might seem to be criticising the Admiralty, but the investigations were taken up without any thought of the Admiralty specification, and simply from the point of view of general trade work. He was very much pleased indeed to hear Mr. Philip's remarks, and hoped that if that gentleman found anything different with regard to the stripping he would let him know, because merely as a question of interest to the trade he would like to know of it. If Mr. Philip saw the way that electro-plated articles had to be treated nowadays by caterers, and in the big hotels, he thought the Admiralty officials would come to the conclusion that such articles were not treated quite so badly in H.M. Navy as they were in big hotels. In some places the electro-plated silver was collected in baskets, and then thrown through a window on to a concrete floor. These were the conditions which the electro-plate manufacturers had to meet.

Mr. W. R. BARCLAY, who also replied, said he wished to make a few additional remarks to those made by Professor McWilliam in regard to the question raised by Mr. Mason as to current density. He had thought several times that current density had a good deal to do with the adhesion of silver to German silver, but the idea had only presented itself to him empirically. In talking the matter over with Professor McWilliam, they came to the conclusion that it would be much better to work on some definite lines, and take the whole series of alloys which covered the ground of commercial alloys, treating them under exactly the same conditions of current density and of plating as obtained in ordinary works practice. So far as was possible in actual practice, precautions were taken to see

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that every one of the series of different alloys was treated exactly the same from that point of view. For that reason the deposits were given in Table II.; and it would be noticed that they were fairly close, considering that they were plated in an ordinary workshop. The thickness approximated roughly to that given to high-class silver-plated goods, particularly spoons and forks, namely, an average of ·0034 inch.

A further reason which influenced them in omitting for the present any specific investigation into the influence of variations in current densities or other conditions of deposition, was the fact that throughout the whole series of their experiments the adhesion of the electro-deposited silver to all the alloys of lower nickel content, and the properties of the deposit itself, were so good as to suggest the unlikelihood of a variation of the conditions having the effect of improving the deposit, on these alloys at any rate, either with regard to adhesion or physical qualities, such as tenacity and hardness.

In reply to Mr. Vaughan Hughes' question, they did not find in practice very much difficulty in casting the German silver, even with a high nickel content.

COMMUNICATIONS.

Dr. R. S. Hutton (Sheffield) wrote that the authors' work was to be welcomed by those connected with the silver-plate industry, as forming perhaps the first scientific attack on the problems which needed elucidation in order to place the process of silver-plating above the level of rule of thumb. The investigation of these hitherto little-studied processes would doubtless lead to important advances.

It must not be forgotten, however, that intimate acquaintance with the difficulties inherent to a manufacturing process often produced a purely empirical *régime* which could successfully overcome them. He ventured to believe that that expressed what was actually the case in the silver-plate trade.

It must be remembered that a number of firms in this country turned out nearly all their work plated upon nickel silver containing much more than 14 per cent. nickel; that the Admiralty and several of the large steamship and hotel companies, and other big commercial concerns who make it a practice thoroughly to test the goods supplied to them, invariably specified a high nickel alloy; that the large American and Canadian railway companies demanded a basis metal containing 21 and 22 per cent. nickel; and that both the manufacturers and the purchasers maintained these standards without apparently desiring any change or discovering at all generally that such a fault as stripping was possible.

Whilst venturing to make these remarks, he wished to offer his complete acceptance and agreement with the authors' experimental results and conclusions, and only to dissent in some measure from the way in which they applied those conclusions.

Undoubtedly, under otherwise similar conditions of treatment, the silver

coating did adhere more strongly to the low nickel than to the high nickel alloy, but he considered that he was justified in stating that, by the exercise of such altered methods of preliminary treatment and electro-plating as had been devised by those who for the past two generations had been occupied with treating the high-grade nickel alloy, the full advantages of the greater strength and whiteness of these alloys could be retained without any cause of complaint under the most trying conditions of wear in hotel and restaurant use.

Professor A. McWILLIAM and Mr. W. R. BARCLAY wrote, in reply, that they thanked Dr. Hutton for his very interesting remarks, as well as for his appreciation of their work.

They were glad that the discussion had produced such clearly expressed differences of opinion on the subjects of the paper ; but they had nothing further to say at present, and would leave those interested to judge for themselves.

Referring to Mr. Vaughan Hughes' "assertion," they had again carefully examined the sample exhibited, and could only say that it did not " warrant this assertion." With regard to the more important differences of opinion expressed, the authors had placed all the essential facts before the Institute, but where differences referred to questions of fact, it would obviously be improper for them to support their views by quoting details of actual cases, and they had no desire to do so. They had pleasure in thanking those members who had taken part in the discussion, and hoped in the future to carry out further experiments on some of the questions raised.

SECOND ANNUAL DINNER

THE Second Annual Dinner of the Institute was held at the Criterion Restaurant, Piccadilly, W., on Tuesday evening, January 17, 1911, Sir GERARD A. MUNTZ, Bart., President, occupying the chair.

There was an attendance of guests and members numbering about 175, amongst whom were :—

Sir ALFRED KEOGH, K.C.B., LL.D. (*Rector of the Imperial College of Science and Technology*).

Mr. H. F. DONALDSON, C.B. (*Chief Superintendent of the Royal Ordnance Factory*).

Sir JOHN FORSEY (*Director of Naval Stores*).

Mr. F. W. BLACK, C.B. (*Director of Navy Contracts*).

Mr. W. G. BUTLER (*Director-General of Stores, India Office*).

Mr. ARTHUR WHITELEGGE (*H.M. Chief Inspector of Factories*).

Sir W. TILDEN, F.R.S.

Dr. R. T. GLAZEBROOK, F.R.S., C.B. (*Director of the National Physical Laboratory*).

Mr. THOMAS L. DEVITT (*Chairman of Lloyd's Register of British Shipping*).

Mr. J. A. F. ASPINALL (*President of the Institution of Mechanical Engineers*).

Mr WALTER F. REID (*President of the Society of Chemical Industry*).

Mr. J. SWINBURNE (*President of the Faraday Society*).

Mr. E. WORTHINGTON (*Secretary of the Institution of Mechanical Engineers*).

Mr. G. C. LLOYD (*Secretary of the Iron and Steel Institute*).

Professor H. C. H. CARPENTER, M.A., Ph.D. (*Vice-President*).

Professor A. K. HUNTINGTON, Assoc.R.S.M. (*Vice-President*).

Professor T. TURNER, M.Sc. (*Honorary Treasurer*).

Mr. T. A. BAYLISS (*Member of Council*).

Mr. G. A. BOEDDICKER (*Member of Council*).

Mr. J. T. MILTON (*Member of Council*).

The PRESIDENT gave the toast of " His Majesty the King," which was drunk with musical honours.

"THE INSTITUTE OF METALS."

Mr. J. A. F. ASPINALL (President of the Institution of Mechanical Engineers), in proposing the toast, said : Sir Gerard Muntz and Gentlemen,—I have the honour to propose the toast of " The Institute of Metals," coupled with the name of your President. Your Institute, which is in the full strength of youth, as I have seen by the figures which your Secretary has been good enough to send to me, has now grown to between 500 and 600 members, and apparently you have a balance-sheet of which you ought to be very proud, having regard to the short period that the Institute has been in existence. There is little doubt, to use an old expression, that you have filled a long-felt want, and while there are many institutions of other kinds, you have found that it is necessary to have one which could deal with all the problems connected with non-ferrous metals ; and a great deal of valuable knowledge has

been demonstrated and set forth in the papers that have been read before your Institute, showing how long much of that knowledge has lain dormant, and how necessary it was that it should be brought to light. There is no doubt that for a number of years many subjects connected with special kinds of alloys were retained within the minds of the manufacturers as somewhat in the nature of trade secrets. Modern knowledge of chemistry and metallurgy is banishing much of that kind of thing, and we probably are all the better for it. I noticed that in a number of the papers that have been read copper has largely dominated the discussion, and I suppose that that will always be so. I believe there is a great deal of money to be made out of copper—at least perhaps our Chairman thinks so. But it was Rudyard Kipling, I think, who said—

> " Gold for the mistress,
>   Silver for the maid,
>   Copper for the craftsman
>   Skilful at his trade."

One can only hope that, if copper forms one of the chief things that you have to deal with, it will enable you to give any amount of gold to the mistress and any amount of silver to the maid. But the alloys of copper are not the only things to be considered, and I have been wondering whether some of the alloys of aluminium might not be of great use in the manufacture of one of those things in which I am interested, namely, railway carriages. Some few years ago I had several carriages built with aluminium panels. They have been so successful that my company have recently built other carriages with aluminium panels ; and I do not see why you who are interested in metals of this kind should not compete with those who are interested in iron and steel. If you come to recollect that the Austrians for thirty years or more have made their carriage panels entirely out of iron or steel plates, it seems to me that there is a fresh opening for something which will be of a lighter character, if it can be reproduced in such a form as to be useful to the carriage-builders. I am not going into the details at this dinner as to the points that are necessary, but I do not know whether anybody would be able at this moment to say that he could produce a jointless panel 63 feet long and 3 feet wide, which would do for some of the modern carriages which are that length, without any opening except at the ends. I see no reason why it should not be done, and it seems to me there is an opening there for some of your younger men to work at. I notice in your Report a remark in connection with the Institution of Mechanical Engineers, in which you thank that Institution for the use of their buildings and their lecture-room. I can only say, as President of the Institution, that the Council have been only too pleased to ask you to come there and to make use of their rooms. I am sure the Council will be proud if you continue to ask for the use of their rooms in order that they may have the pleasure of saying " Come again." I venture to suggest, without presuming to advise, that there is a thing in connection with that building that you might take account of. I daresay you may not know that the Institution of Mechanical Engineers are about to add considerably to their block of

buildings. They require a good deal more room for their own work; but they intend to erect a building which, for the present, at any rate, is beyond their own requirements. When you go to that Institution to-morrow to carry out your business programme you will see at the corner of Princes Street a large hotel—though I think some people call it a public-house. The proprietors of that establishment, knowing that the Institution of Civil Engineers was about to build on the other side of Princes Street, knowing that the Institution of Mechanical Engineers wanted to enlarge their premises, and thoroughly understanding what a temperate lot all engineers are—being absolutely satisfied in their own minds that the engineering spirit was much more important than the spirit of the distiller—came to us and asked us to purchase their build-ing, and it is now our property. The result is that we are going to build a considerable addition to our premises; and I suggest that your Presi-dent should consider whether it is not better for the Institute of Metals to have their home in such an engineering centre rather than upon the site of an old aquarium. You see, a large number of your members are already members of the Institution of Mechanical Engineers, and some of them are members of the Institution of Civil Engineers, and it would be an immense convenience to all those gentlemen if they were in close proximity to this great engineering centre. And fortunately, I think, your Institute and our Institution have been connected ever since you started by a metallic filament which has thrown the greatest possible light on many engineering subjects, and I see no reason why both of us should not remain within the centre of that illumination. Gentlemen, I have now to congratulate you upon the advantage that you possess in having Sir Gerard Muntz as your President. I am sure that his position in Birmingham, his great personality, and his wonderful youthfulness are among the great advantages that you possess; and I ask you to drink to the health of the Institute of Metals, coupled with the name of your President.

The toast was heartily honoured.

The PRESIDENT (Sir Gerard Muntz, Bart.), who was heartily cheered on rising to respond, said: Mr. Aspinall and Gentlemen,—I thank you, sir, for the very kindly way in which you proposed this toast, and the too flattering terms in which you have referred to myself; and you, gentlemen, for the kind way in which you received it. In drinking the toast of the health of the Institute many of you are drinking your own healths. I hope a future President may have the pleasure of feeling that even more members are drinking their own healths. With regard to Mr. Aspinall's remarks, I am sure the Institute fully appreciates all he has said with regard to the widening of the scope of their researches as much as possible. Speaking as a manufacturing member of the Institute, I am sure we shall be only too willing and pleased to amplify our present classes of manufacture. I am sure all manufacturers of metal will only be too willing to go into the question, not only of copper, but also of aluminium. But you are asking rather a large order from the aluminium makers to-day, I think,

when you ask for a sheet 63 feet long. I do not say it cannot be made, but it will take a little care and practice to make it. With the assistance of our scientific friends in the Institute I am by no means hopeless that, with a little added knowledge, we may even attain to that. I know that all the practical members are seeking ways and means to meet the requirements of the engineering fraternity. That is really the object of all manufacturers, to meet the requirements where possible — it is sometimes difficult to do so—of the engineering fraternity. I have hopes that in the future we shall be able to carry out the suggestion kindly put before us by Mr. Aspinall in that respect. With regard to your kind suggestion that we should come and live under your roof if possible, that I am sure most of us—in fact, I think all of us—would be only too pleased to do so. But, gentlemen, there is always a little matter which has to be considered, especially by my next-door neighbour but one, our Treasurer, who always has to bear these matters in mind, and that is the question of £ s. d. This Institute is a very young Institute. Although Mr. Aspinall has been good enough to say we should be proud of our balance-sheet, we cannot afford to be extravagant and chuck our money about. We have at the moment a small home in Caxton House, and we have a lease. We may get rid of that lease by-and-by, and if the Mechanical Engineers are feeling generous, and their terms are not too onerous, and we can see our way to get rid of our present abode profitably, I think we may be only too pleased to come to the Mechanical Engineers' building. I would not suggest this seriously, sir, but you have heard of the cuckoo, and although you are a very large bird at present, and we are a very small one, yet it is sometimes a little risky to take a small bird into a big bird's nest. But the matter will, I am sure, receive the serious consideration of our Council, and I hope we shall be able to consult with our friends the Mechanical Engineers by-and-by, and see what can be done. I am sure we are all very grateful for the kind way they have treated us up to the present, and our experience of the Mechanical Engineers' hospitality as hosts almost leads me to believe that we may be certain of finding them good landlords, though it is not always the same thing. We are gathered here to-night for the second time at one of these annual banquets. Our meeting on this occasion is a little bit upside down. We should, under ordinary conditions, have dined after we had attended to business, on the principle of first work and then play. But on this occasion it so happened that we were honoured by an invitation from the Thames Ironworks and Shipbuilding Company to witness the launch to-day of His Majesty's ship *Thunderer*. Unfortunately, as you know, the launch was postponed. But that was the reason why we altered the form of our meeting; we should have had the business meeting to-day otherwise. Nevertheless, I daresay that we shall manage to get our business just as well done after dinner as before ; we may anticipate that something good may happen to-morrow. I am very pleased, as your President, to be able to congratulate the Institute on an increased attendance here to-night, and to see that the Institute is growing—slowly perhaps, but

it is a bad thing for children to grow too fast. If the body grows too fast it affects the brain, and I should not like to think that the brain of the Institute was being affected in any way by a too rapid growth. At the same time, I like to see healthy growth going on, and I think that is the position we are in. We have increased considerably in the course of the last twelvemonth, in spite of serious losses. I had rather an astute remark made to me yesterday by a working man in connection with the Institute and its work, in which he was very much interested. Referring to the knowledge which is being distributed by the members of the Institute and by the papers read and discussed, this working man, referring to a certain person, said that he found that he was improved very much by having read some of the papers, and continuing, said, " I find, sir, the more a man knows the less he suffers from swelled head ! " There is a great deal in that remark. I should not like to suggest for a moment that any of our members have suffered from that disease, but I do hope that we shall all feel somewhat a shrinkage of the cranium, because that will denote that we are increasing in wisdom. If we feel that, although our knowledge is developing, the size of our cranium is smaller, we shall realise, in the light of our friend's remark, that if we suffer from swelled head it is because we have less brain power. It is rather an Irish way of saying things, but it is quite true, and I am sure the papers that have been read before the Institute, and that we shall hear to-morrow, will teach us that lesson. I do not want to make too serious a speech to-night, because I feel this is an occasion on which we are gathered together for amusement, for rest, recreation, peace and quietude—if we can get it. But although we are peaceful and quiet to-night, and everything is happy, to-morrow I believe we may look to seeing war—to the rending of members one by another— to the tearing, not of coats—I do not know exactly how to describe it— but there will be fur flying. Therefore, while you can have peace, have peace : let the lion lie down with the lamb. Perhaps you will ask, Who is the lamb and who is the lion ? Speaking as a manufacturer and an innocent maker of goods, I should say the manufacturer is the lamb, and that the lion is possibly the consumer. What we are to do with the poor scientist it is rather hard to say at the moment ; he occupies a kind of ethereal or angelic position ! You recollect the ancient proverb of the wolf and the lamb, in which the lamb was supposed to churn up the water and make it muddy, and the wolf had to drink it, although the wolf happened to be upstream. If between the wolf and the lamb there could have intervened a scientist, I am quite sure the wolf would never have quarrelled with the lamb, because the scientist would have explained to the wolf that water could not run uphill, so that there was no possibility of muddying the water. But, unfortunately, the manufacturer is the lamb ; he is supposed to muddy the water, and he gets all the blame. We look to the scientist to explain to the consumer that water cannot run uphill, and therefore that faults cannot always be attributed to the poor, unfortunate, honest manufacturer. I think that, speaking gener- ally, we have learned a great deal in the two years and three months since we made a start. I think we may congratulate ourselves that in

two years and three months we have accomplished as much as we have ; and when we take into consideration the advice we have received from our friend, Mr. Aspinall, to-night as to the development of our researches into new metals, I am sure we shall not be short of new fields to conquer for some little time to come ; and we may hope that, even if we do not attain to that excellence which is sometimes expected of us, yet we may make some progress towards justifying our Institute's existence. Gentlemen, I thank you.

" KINDRED SOCIETIES."

Professor T. TURNER, M.Sc. (Hon. Treasurer), in proposing the toast, said : Mr. President and Gentlemen, —It is with mixed feelings that I rise to-night to propose to you the next toast, that of " Kindred Societies," because I had hoped that the toast would have been taken by another member of the Institute, one who has done much more for the Institute than I have been able to do. But unfortunately, on account of ill-health, the duty has devolved upon myself at comparatively short notice. You have heard that our Institute is a young and vigorous member of a very large and rapidly growing family, the family of the learned and scientific societies. It is nearly 250 years since the first scientific society, the Royal Society, was established, and since then, one by one, other learned and scientific societies have come into being, each having its own duty to perform, and, in the majority of cases, we may say, well doing a very useful work. You will have noticed that these societies are generally called the learned or scientific societies, from which you gather that the learned societies are not scientific ; but I think we should object, on the converse, if it were said that the scientific societies were not learned. These societies have done us honour in various ways. In the first place, in connection with our formation they helped us very materially. They have housed us, they have given us advice, and they have given us sympathy, and if there had been no other scientific society but our own, I feel sure it would have taken us very much longer to have been able to accomplish the good work which we already have done. And they have complimented us, too, in various directions, I believe, by claiming that we, as metallurgists, are really only their children. I find that we are claimed as being a branch merely of the engineers ; that we are the children of the chemists ; that we are closely associated with the physicists ; and I do not know how many other of these learned societies claim that metallurgy is a little branch of their field. When I meet a chemist, at the present time, I am not quite sure whether I ought to regard him as my father or as my son—of course, I mean as a metallurgist. Because, though it is claimed that metallurgy is but one small corner of the wide field of the chemist, one remembers that alchemy existed before chemistry, and that the alchemist was only trying to do, in a clumsy way, what the metallurgist could already do in a better manner. So that I think I incline, on the whole, when I meet a chemist, to look upon him rather as a son than as a father, and to take considerable pride in his very remarkable growth. We are, as I have said, deeply

indebted to these societies for the help they have given to us, and for the lead they have given us. The importance of the scientific societies can be judged often by the difficulty we should experience in finding information and knowledge if such societies did not exist. The best of our knowledge is not contained, as a rule, in our text-books, nor is it contained even in the lectures of our eminent professors, because, after all, they can only give us but a short outline of the subject which they have to teach. But when we come to search further into our subject, and we desire to know that which has been done accurately and well, it is to the records of the learned and scientific societies that we turn, and in those we find our chief treasures. We have represented here to-night several of the societies which are closely associated with our own. I am sorry that we have not even a larger number of societies represented, because the metallurgist trenches more or less upon the province of a great many of the other societies ; that is to say, we dovetail in our work with the chemist, who, of course, is at the basis of much that we do ; with the physicist ; with the geologist ; even with the mathematician ; and particularly, nowadays, on the practical side with the electrical engineer, with the mechanical engineer, with the civil engineer, and with all the men who have to do with the handling of materials in large quantities, or in assisting us to produce a rapid output. Of the societies that are represented here to-night, we have, on the one side, the Society of Chemical Industry. Some of us have been members of that Society for many years, and those who are familiar with its Journal must acknowledge the great advantage that we always derive, particularly from the abstracts, which are so carefully and well done in that Journal. Only last night I was reading my Journal, and I found there an abstract of a paper bearing upon a subject in which we are very much interested in my own laboratory at the present moment, and the information I there obtained gave me knowledge which I could put in the hands of a student of that subject, which to him is of such great importance. We are, therefore, very glad to have with us to-night the President of the Society of Chemical Industry. The Faraday Society brings before us a name that will always be honoured in connection with English science, and deals with a branch of work which touches very closely upon many branches of metallurgy ; and in the *Transactions of the Faraday Society* occur, from time to time, papers which we read with very great advantage. In reference to the Institution of Mechanical Engineers, it would be very difficult for a member of the Institute of Metals to speak with sufficient feeling. From the very first they have helped us. We had their President with us on the original Council of the Institute of Metals, and we are very happy to have with us to-night and to have heard the voice of their President for the year. But I have to couple with the toast, on behalf of the Institution of Mechanical Engineers, the name of the Secretary of that Institution, Mr. Worthington. In doing so, I should like to say that we are specially indebted to the courtesy, the kindness, and the sympathy of Mr. Worthington from the very beginning of our work. I have, myself, specially referred to him, and I have endeavoured to put our own Secretary in touch with Mr. Worthington, knowing that he could have no

better helper or instructor. Mr. Worthington has done all that he pos-
sibly could to assist us in connection with the Institute. We are, there-
fore, indebted, not only to these societies, but to their personal repre-
sentatives who are here to-night, for what they have done for our
Institute. I have much pleasure in proposing the toast of " Kindred
Societies," coupled with the names of Mr. Reid, President of the Society
of Chemical Industry ; Mr. Swinburne, President of the Faraday
Society ; and Mr. Worthington, the Secretary of the Institution of
Mechanical Engineers.

The toast was duly honoured.

Mr. WALTER F. REID (President of the Society of Chemical Industry),
in responding, said : Mr. President and Gentlemen,—I am very much
indebted to you for the kind words that you have spoken about the
Society which I have the honour to represent. You have raised the
question whether chemistry should be the parent, or whether metallurgy
should be the parent ; and I am inclined to think you are quite right
when you say that metallurgy was one of the first industries that was
created by the human race. At any rate, so far as we know, some of
the very first artificial products that can be attributed to chemical
industry were the metals, particularly copper. There are many other
chemical industries that might be brought in in this connection, but
I think there is no industry that has promoted the welfare of the human
race more than the industry of metals and their use. That use has
been so great and so multifarious that you have formed a Society dealing
with one branch of it alone, as I understand. You exclude one metal
which is perhaps more in use than any other, and which is produced in
quantities exceeding the others. But I am inclined to think the time
will come when steel and iron may lose its dominant position. By
degrees other metals are getting in edgeways, as it were. Iron alone
is not sufficient now for the purposes of national defence ; you have to
go to nickel and to other metals which are absolutely necessary for the
new purposes to which we have to look in connection with our national
defence. With regard to copper and aluminium, which have been
mentioned, it seems to me that, from the chemical point of view, in
which I am specially interested, there is a great deal to be done with
regard to copper. Those of you who have had the advantage of seeing
some old Peruvian monuments will remember the enormous monoliths
of the very hardest basalt—great blocks of stone as big as the curtains
hanging in this room, which were built into gigantic walls. Each block
of stone is cut to fit into the other ; the stones are not laid in courses at
all ; and the whole of that work was done, so far as we know, with
copper tools. That is a point the metallurgist has not yet solved—how
a copper was produced with which the people could carve the hardest
stone. There is a very great future indeed for any one who will produce
a copper of that kind, and if they do it will naturally supplant a great
deal of the steel used for some purposes at present. Then there is a
very large field with regard to alloys that has as yet only been touched,
namely, in connection with aerial navigation. We want there very

badly indeed metals that are continuously reliable, and which do not oxidise rapidly. I happen to be the Chairman of the Laboratory Committee of the Aeronautical Society. That committee is testing a number of metals and different materials for aeroplanes, and the want of a reliable alloy which is light and strong is undoubtedly very urgent. One reads a great deal in the Press about such alloys appearing from time to time under very eminent auspices, but there is generally a "but" about it. It requires careful examination by such a Society as your own to make quite sure that a man can depend upon such alloys for his life. Incidentally I may indicate a cause of some of the lamentable accidents that have happened in regard to aeroplanes. Aeronauts in constructing their machines take the very strongest wire they can get, bicycle or piano wire. That wire is already strained to the utmost limit that it will stand, and the moment it is strained beyond that limit it becomes weaker. When an aviator goes up in an aeroplane the wires are taut; when he comes down the wires are slack. He then sometimes screws the nut up just a little, and more than one man's life has already been lost through that overstraining of the wires which stay the aeroplane. A metal is required which is strong, but I do not think aeronauts ought to use a metal that is readily oxidised, because this metal is greatly exposed to oxidation. Then with regard to aluminium, that is of course a metal that is coming very much to the front as it becomes cheaper. The pioneers in the aluminium industry were rather unfortunate. When that metal was 25s. a pound I joined some friends in starting a company for its manufacture. We found, however, that when we had made a few tons the price went down; we had swamped the market. Most of you know the present price of aluminium. A few weeks ago I happened to be in the South of France, and I looked with envy at the great big bars of aluminium by means of which an enormous electric current was being sent from the generating plant to a factory, in which they were making 98 per cent. nitric acid from the oxygen of the atmosphere. That enormous application of electricity nowadays is a subject that must be of the very greatest interest to your Society. New alloys are possible now which were quite impossible only a few years ago. There has been much trouble in France recently about automatic lighters. The matches were so bad that people took the very best material they could find to get a light from. What did they take? They took a new alloy. Those lighters were made with a new alloy, and you can see from the figures given in the Press how rapidly the sale of such an alloy has increased. I should like to relate one little episode with regard to the expansion of the use of a metal that may interest you. Many years ago I introduced a method for silvering glass: it is now the universal method. It consisted in using silver instead of mercury; and was based on Leibig's method of precipitating silver from solution in the metallic form. But when I took that method to a manufacturer who made mirrors by the old mercury and tin process, he said to me, "Well, how much is silver an ounce?" I said, "About five shillings." He replied, "What is the good of trying your method then? I cannot look at it; it is no good."

I started a factory for the manufacture of mirrors, and before the factory had been in working order a year I sold out of it at a good profit, and now all mirrors are made in that way. The illustration shows that, even although a thing does not appear hopeful at the moment, if it meets a want it is very well worth going on with it. Some of the younger members of this Society have an enormous future before them. As I was saying, the power that you have now in your hands by means of electricity of producing metals and alloys is a thing that was undreamed of when I was a student of metallurgy in Berlin. In those days, in the testing of alloys we had very crude methods compared with those which exist now, and I am inclined to believe there is a still greater future before us. We have at the National Physical Laboratory, of which I have the honour to be a governor, an apparatus with which we take photographs by means of ultra-violet rays. We therefore get a visible image from light which is invisible to the eye. I believe the work is rather troublesome to those who undertake it because you cannot focus by eyesight. There are many other rays that are still unknown to us, and those may be used in future. For instance, in the testing of minerals I have used a method which, so far as I know, was original. If you take a polished section of a complex mineral, expose it to rays of various kinds, and then impress the polished surface on a photographic plate, the minerals in some cases will photograph themselves. I am not speaking of radio-active minerals, but of those exposed to the bombardment of certain rays. I think you could apply that method to metals also ; at any rate it is worth trying. In conclusion, sir, I thank you very much indeed for the kind words you have spoken with regard to our Society. We do hope that our Journal is of use to you. You will pardon me as a member of an older Society for looking upon yours as a younger branch. But we will not cease to devote a section in our Journal to things connected with metallurgy and with alloys in every way, though of course your own publication will develop and grow, and you will probably be the authorised source of all information throughout the world on the subjects with which you deal. But at the same time, if I may be allowed to give you a hint as you are growing, I suggest that you should take a leaf out of our book and make your Society an International Society, an Imperial Society. We, the Society of Chemical Industry, have branches all over the world. We have two branches in the United States ; we have branches in Canada and Australia, and we are now starting a branch at the Cape. I think if you make your Institute an Anglo-Saxon Institute you will add to your numbers, and add above all to the increment of human knowledge which we are all interested in increasing.

Mr. J. Swinburne, F.R.S. (President of the Faraday Society), who also responded, said : Mr. President and Gentlemen,—We have heard a great deal to-night about questions of parentage, and I would like to point out that most of the theories that have been put forward on that subject so far are entirely wrong. Some time ago I met a man in the street who did not know what the Faraday Society was. I do not mean

to say he had never heard of it, but he did not know very much about it. So I may tell you at once that the Faraday Society is one of the many excellent inventions of Mr. Sherard Cowper-Coles, and the object of the Faraday Society is to embrace all branches of natural science that are not already taken up, or would not afterwards be taken up, by other special societies. We have heard this evening how the various sciences were fused together, and now they are gradually crystallising out and separating. We, the Faraday Society, are a kind of mother liquor. When we were originally formed, the metallography and the science of metals, except iron, was part of the work of the Faraday Society, until you crystallised out, and now we regard you as a kind of colony. I do not mean that you are microbes, but we regard you as a kind of flourishing colony of the Faraday Society, and any other society that claims the parentage of such a flourishing body as the Institute of Metals has no ground at all for any such pretensions. Going to another point, I sometimes wonder whether any one of you has ever tried to read the literature produced by any other member of your Institute, because sometimes, when I feel in a frolicsome mood, I have tried to read articles on alloys for the purpose of making out what on earth it is all about. I experienced great difficulty till I came across a solution of one of my chief troubles. One difficulty I had was that the nomenclature always made me doubt whether I was reading about geological specimens or explosives. But my chief trouble was your diagrams. I always came across something which appeared to be a section of some potted calf's head, or some rice pudding, or some other esculent conglomerate; and after reading the letterpress I found it did not much matter what illustration you referred to. I came to the conclusion, after thinking it out carefully, that the people who prepare the blocks are really having you, and having you rather badly. What happens, I confidently believe, is that when you get a paper of your own they pass off on you some old pathological diagrams, and when you think you are reading something which proves some very difficult and impossible theory about a phase rule, what you are really looking at is a second-hand block of a microphotograph of a diseased liver. And when I find an article referring to one of these illustrations which shows a beautiful, well-formed crystal of tomite, in a mother liquor of dicteite, with stars and stripes across of parryite, then I know that what you are really looking at is a microphotograph of the swelling of the head of some actor, or politician, or popular novelist. I have to thank you very heartily for the kind way in which you have drunk the health of the Faraday Society, and of me in particular; and I can only say, in the words of a greater orator than any one here present now, "Gentlemen, I thank you very much."

Mr. Edgar Worthington (Secretary of the Institution of Mechanical Engineers), who also responded, said : Mr. President and Gentlemen,—I rise with a certain amount of timidity to reply to this toast, as I observed as soon as I entered this room that there were three or four members of my Council present, and I had previously intimated to the Secretary of the Institute that I could not reply to the toast if they

were here. I hope, therefore, that they will forgive me for doing so against my intention. The Institution of Mechanical Engineers does appreciate the visits of your Institute to our building at Storey's Gate, and speaking on behalf of the staff and myself, I can only say that we are always very pleased to make the small arrangements which are necessary for your meetings. If a representative of each of the engineering and learned societies of this country were called upon, you would have to listen to some fifty-six speeches before this toast was satisfactorily replied to. Some of those societies have wide interests, but I think there is not one which professes to cover the range of subjects which one of our kindred societies across the water attempts when it asks for papers dealing with the manufacture of almost any material from firearms to glue and "time study." Professor Turner, in the kind words he has applied to kindred societies, referred to a function which I consider one of their most important duties, that is putting before the members particular information which is stored up in those dusty, brown, blue and other coloured Transactions lying so neglected upon the shelves of many of our libraries. Every one of those volumes contains many grains of metal, but there is to most minds an interminable heap of dross; and I, as an officer of one of these societies, think that it is one of our chief functions to be able to give to the members those grains of metal, and to save them trouble which they must otherwise take in hunting for that metal. We are much better able to do that work nowadays than in days gone by. If you look into English history during the seventeenth century, it is said that in the King's library there are some fifty thousand copies of newspapers and pamphlets which are not indexed; and historians, I am told, when they try to search out their own period in that century, have found that it is almost a life's work to obtain the information they want. It must have been very difficult a century or two ago to collect precise information. But now we have scientific and learned societies whose indexing, although not perfect, is good; and if the members of the various societies would only write to their secretaries and put their problems to them, I am sure that each of those fifty-six societies might render a large amount of assistance to its members.

"The Guests."

Mr. G. A. Boeddicker (Member of Council) in proposing the toast, said: Mr. President and Gentlemen,—I have the pleasure to propose the next toast, namely, that of "Our Guests." This toast should have been proposed by Sir William White, who unfortunately is absent through illness. You, gentlemen, therefore, instead of listening to the melodious voice of our late President, will have to be satisfied with what the Press sometimes calls the guttural voice of the Fatherland. Gentlemen, our guests are our friends. The friendship of those of them who are here as distinguished representatives of kindred societies and scientific institutions was never doubted for a moment, but it is rather different with regard to the heads of important public departments who are here to-night. I am very sorry to say that sometimes this friendship, this *entente cordiale*, is inter-

rupted, although only for a short time. I am sure there is nobody here who is a manufacturer who has not at some time sat down in desperation when reading through a new specification, be it for naval brass, or condenser tubes, or even nickel. The manufacturer has sat down and torn his hair, and said, " It cannot be done "—and then, he has gone and done it. It is the same when you get one of those amiable letters from the friend on my right, with " C.I.F." on the outside of the envelope, which means not what you generally understand it to mean, but " Chief Inspector of Factories." You perhaps get an order to instal some more easy-chairs and couches in your casting-shops for the benefit of the brass-casters, and you sit down and tear your hair again, and say, " Is it better to go out of business or to accept these regulations ?" But, gentlemen, you are all here to-night, and you have not gone out of business. What these friends have done for us is what the Institute is doing for us now. They have been our real friends, and their action has spelt progress. It is largely due to their difficult specifications, and to their regulations for our factories, that the British metal industry occupies the proud position of one of the first in the world. Gentlemen, I was rather surprised to find so many guests here. I was very diffident myself as to whether I should come or not to-night. If you have a scientific-practical man as a President, and a Professor as a Treasurer, and a Master of Science as a Secretary you must be prepared for anything, and I was quite prepared for anything when I came. The first thing I did was to look at my chair, because I thought very likely all the chairs had been fitted up with a self-registering extensometer for the purpose not only of showing scientifically the effect of a good dinner, but perhaps to arrange for the payment of it by results. I have also noticed that Mr. Shaw Scott, our Secretary, has been scribbling all the evening, and I have a strong suspicion that he has been drawing solidus and liquidus curves of all our guests for publication in the next Journal. And even then I am afraid of something else. I am afraid that when we file out to-night the curtain opposite may be drawn back and disclose our Treasurer, Professor Turner, with his favourite blackboard, and that we shall see him drawing with his beloved chalk, while we file past, equilibrium diagrams of every one of us. Gentlemen, I propose the toast of " Our Guests." We are very pleased to see them here, and to think that they have braved all these possibilities. I couple the toast with the names of Mr. Butler, Director-General of Stores, India Office ; Sir John Forsey, Director of Naval Stores ; and Sir Alfred Keogh, Rector of the Imperial College of Science and Technology.

Mr. W. G. BUTLER (Director-General of Stores, India Office) in responding, said : Mr. President and Gentlemen,—I address myself to a pleasurable task, in which I shall express the feelings of at least one-third of the guests, which I believe is the proportion allotted to me. Those feelings I am sure are those of the greatest cordiality for the hospitality which has been extended to us. I have dealt with the question of metals personally for some thirty or forty years. I have usually had to deal with copper, iron, and steel. On this occasion I propose to

leave out everything connected with metals, with the exception of quoting our old friend Horace; but instead of saying, "Auri sacra fames" I will say "Zinci sacra fames." The man who brings the price of tin up to £210 a ton ought to be sacrificed to the Muntz Metal Company! We always realise in Government offices that the manufacturer is only second to the importer. There are so few metals that are not imported that we are practically in the hands, I believe, as a rule, of foreigners. If we were not in the hands of foreigners, and if tin could be purchased in Cornwall, what a change would come over the price! How much more profit would Muntz metal make at once! Although I am making these personal remarks, I know Sir Gerard does not mind ; but I do think it is a pity that we should all be sitting here in this quiet sort of way, and thinking how nice it is to have tin at £185 13s. a ton because we bought at £150 a ton, and then to-morrow we find some move in the market and then, "Where is copper? Dear me, why, I bought at £65 15s. and now it is £56 15s." That change is brought about by the foreign producer, and has nothing to do with us in any possible way. I can only add, on behalf of my 33 per cent., which is a pretty good dividend of the company present as guests, that I trust the Institute of Metals may be *aere perennius*, and looking round I think we may say, in regard to the empty bottles, "*Si monumentum requiris, circumspice.*"

Sir JOHN FORSEY (Director of Naval Stores), who also responded, said : When I was asked to attend your banquet to-night I accepted the invitation with a very great deal of pleasure, because I knew a great many of your members. Later, when it was suggested to me that I should at all events make one of the responses to your kind toast of "The Guests" of this evening, I felt it would be ungracious of me to decline ; but I am bound to say it has been rather at the expense of my dinner, as all through dinner I have felt myself very much in the position of the poor man who had just buried his wife, and who, on returning from the funeral and experiencing something or other which upset him, said, "Well, you've spoilt my day, at all events." From what I have already said you will at once gather that I am no hand at public speaking, but wherever I go I always try to learn something if I possibly can. With regard to metals I have, as head of the department which I have the honour to represent, rather a lot to do with metals in the course of the year, amounting to some hundreds of thousands of tons, and I thought I knew a little about the subject. But to-night I have learnt my limitations in this respect, and I now realise that I know practically nothing about metals. However, I think I learned something the other night. I was dining, as on the present occasion, with a very learned Society. They were giving a dinner to their previous Vice-Presidents. The President of the evening, in proposing the toast of these five gentlemen, read us a biography of each, which occupied exactly thirty-seven minutes by my watch. Each of these five gentlemen followed, and in turn gave us a complete history of the particular branch of the science in which he was interested. It was all very interesting, but that occupied another hour—I am not

exaggerating. When they had finished, the President of the French Society was asked to speak, and he gave us about twenty minutes more of a discourse in the most perfect French, at the conclusion of which the President of the German Society was called on, and, much to my admiration and that of everybody else in the room, he gave us a good lengthy speech in very excellent English. Then he said, " But, gentlemen, I am not good at the language. If you will only let me speak in my mother tongue I can tell you something," and he weighed in with another speech in German, the precise duration of which I cannot say, as I had to leave before its termination, leaving behind me the Duke of Northumberland, the Postmaster-General, and several other very prominent men, all waiting to speak to their respective toasts. I then vowed that if ever it was my lot—I will not say misfortune, I will say pleasure on this occasion — to make an after - dinner speech, or an attempt at doing so, I would be very brief indeed ; and I feel sure that you will say that I am right in doing that. In using the term "doing right," I am reminded of an American gentleman who was noted for being very short and concise in his speech. His son had just arrived at man's estate, and was about to leave home for business life. The father thereupon called his son into his study, and said, " My son, I am going to give you some advice. *Do right*, and fear no man ; *don't write*, and fear no woman." I think you will thank me at this stage if I resume my seat, but I cannot do so without thanking you very heartily for the reception you have accorded to your guests to-night. Some one—I do not quite know who it is, or where it is, but I know that I have read it somewhere—has described gratitude as " a lively anticipation of favours to come." In returning you our thanks, as your guests this evening, for your kindly and bounteous hospitality, I can only say that if you choose to read into that remark an intimation that perhaps we would like to come next year, I shall have nothing to say against it. I thank you very heartily indeed for the cordial reception you have given me, and for the further honour you have done me in coupling my name with this toast.

Sir ALFRED KEOGH, K.C.B. (Rector of the Imperial College of Science and Technology), who also responded, said : Mr. President and Gentlemen, —As the evening is wearing on, I shall simply content myself with joining with my fellow responders in thanking you for your great kindness in asking us to dinner to-night. Perhaps that would be sufficient, and I feel that you would regard it as sufficient reply, but I may perhaps be allowed just to say a word with regard to the College over which I have the honour to preside. As a matter of fact, the formation of an Institute of this description is one of the utmost importance to us as well as to you. I hold very strongly that a great educational institution cannot properly fulfil its function unless it is in touch with the practical necessities of the day. That is a principle which applies, not merely to science, but even to the humanities, and for that reason I am glad to know there is yet another scientific Institute to which we, in the Imperial College, may in time look for guidance in our educational methods. I under-

stand that at present you have not considered the question of education in your particular direction, but I do earnestly hope that you will lose no time, when you get other questions out of the way, in considering how best you can help the great educational institutions in this country in training up young men in the direction in which you, as practical men, know they should be trained. We have heard much to-night about the manufacturer, and we are hearing constantly, not only at these dinners, but in scientific papers and in the daily papers, that the manufacturer in this country does not really appreciate science. My own personal opinion is distinctly that the manufacturer is not nearly so much to blame as the purely scientific man. I believe myself that the educational institutions are much to be blamed for the conditions which exist at the present moment. I think that the professorial type—I say it with fear and trembling, but perhaps I may be excused—tends rather in a big educational institution to get into a groove, and I think it is the duty of the governing and administrative bodies of these institutions to place themselves in the closest possible touch with the industries outside and with practical men, in order that the education within the institutions shall be directed along the lines laid down for them by the practical men. For that reason I hold very strongly that we, in the Imperial College, must in time look to you, if you will be so good as to guide us, as to our methods of education. I cannot doubt for a moment but that you regard education as of enormous importance—that goes without saying; but I do think that you have a responsibility in connection with that education which you practical men too often leave to the educational institutions themselves. The time has come when you should consider the students within these colleges as depending upon you for advice through their own professors and administrators as to the course they should pursue to obtain a really practical knowledge of the subject on which they have to live. That I feel sure is all I need say on that subject. I again most warmly thank you for your kindness, and on behalf of my 33 per cent. of the guests, for the charming evening you have given us.

BIRMINGHAM LOCAL SECTION.

A MEETING OF THE BIRMINGHAM LOCAL SECTION OF THE INSTITUTE OF METALS was held in the University of Birmingham on Tuesday, December 13, 1910, when Mr. O. F. HUDSON, M.Sc., delivered a second lecture on "An Introduction to Metallography." *

Professor TURNER took the Chair and made an apology for the unavoidable absence of Mr. G. A. Boeddicker, the Chairman of the Section.

The CHAIRMAN then called on the Secretary, Mr. R. M. Sheppard, to read the minutes of the last meeting, which were adopted.

The CHAIRMAN announced that Mr. F. Johnson, who was elected Treasurer of the Section, had been appointed Lecturer of the Swansea Technical School, and Mr. S. M. Hopkins had consequently been asked to take the place of Mr. Johnson, and had consented to do so. In connection with the membership of the Local Section it was not compulsory to reside in the neighbourhood of Birmingham to join the Local Section.

Mr. O. F. HUDSON, M.Sc., Special Lecturer in Metallography in the University of Birmingham, then delivered the second portion of his paper on "An Introduction to Metallography," of which the following notes constitute a résumé :—

When two metals form an intermetallic compound it not uncommonly happens that this compound decomposes on melting, and is not represented by a maximum on the freezing point curve. The equilibrium diagram for a series of alloys in which such a compound exists was explained in detail, and was followed by the consideration of the diagrams

* [Some notes on Mr. Hudson's first lecture appeared in the *Journal*, vol. iv. —ED.]

for alloys of two metals partially or wholly soluble in each other in the solid state. The constitution of two series of alloys of commercial importance (the brasses and the bronzes) was next dealt with, and their microstructure explained and illustrated by the aid of lantern slides. The separate, and quite distinct, homogeneous substances or phases which make up alloys are of three kinds, viz. solid solutions, pure metals, and compounds. Pure or nearly pure metals are not commonly found in alloys, and the most important substances are solid solutions. Almost all malleable and ductile alloys are essentially solid solutions, and the majority consist of a single solid solution. In a cast alloy the crystals of a solid solution are not always perfectly uniform, and when examined under the microscope a cast solid solution shows this want of homogeneity by the characteristic " cores " or skeletons of the crystals. On annealing, each crystal becomes quite uniform, a result which is brought about with greater readiness if the alloy is first rolled or otherwise worked. Annealing after rolling also leads to crystalline growth, which increases with the time and temperature of annealing. Metallic compounds are hard and brittle, and by themselves are mechanically useless. They are, however, present in some alloys and serve a useful purpose. Many alloys consist of more than one phase, and a eutectic, although always considered as a distinct metallographic constituent, is a mixture of two phases in a binary alloy, or two or more phases in more complex alloys. Eutectics are usually hard and brittle unless they are mixtures of malleable substances, and since they are the most fusible constituents of alloys they form in some cases a network or cement of brittle material between the other crystals. Some of the most useful alloys, such as Muntz's metal and special brasses, are made up of mixtures of two solid solutions which are not eutectics, while mixtures of a solid solution and a eutectic, or a hard compound, or mixtures of all three, form many alloys which are specially adapted to resist wear or compression. The lecture was illustrated with lantern slides showing equilibrium diagrams and crystalline structures of different alloys.

At a further meeting of the Local Section, held in Birmingham on February 14, 1911, under the Chairmanship of Professor T. Turner, M.Sc., Mr. G. A. Boeddicker, Chairman of the Section, read a paper entitled " A Visit to some Rolling-mills in America," of which the following notes constitute a résumé :—

Mr. Boeddicker said that " a visit to the United States should be part of the education of every member of the Institute of Metals. Owing to the different conditions and the different position of the labour market the metal industries in America have developed very rapidly and on different lines, and if we mean to continue to progress in this country it is absolutely necessary to see what others are doing ; not perhaps with a view to adopting every improvement, because methods might be economically right in the United States which would be economically wrong here.

" A visitor once introduced, meets with extraordinary hospitality and is treated in a perfectly open manner, but it is expected of him that he answers every question put to him without reserve, and that the works he represents in England is open to American visitors. Unfortunately it has happened lately that visitors have got into American works under false pretences, and there seems an inclination to be more careful in admitting strangers.

" *General Impression.*—The first thing which struck him was the extravagant use of land. Works are built outside the towns, land is cheap and consequently have been planned with a free hand. Quick development on large lines, facilities of cheap transport to and inside the works, standardising of qualities and sizes and working at high pressure have enabled the American works, in spite of high wages, to compete with Europe.

" The works are well up-to-date and kept clean and in good order. The boilers are mostly water-tube boilers. High-speed engines are practically absent. The rolling-mills are driven direct or through a jack-shaft by slow-running engines, and electricity is employed to practically all the supplementary machines and the wire mills.

" *Raw Materials.*—For the alloys, specially for German silver

only the purest metals are used. Spelter with less than 0·4 per cent. of lead and the purest copper obtainable; there is very little scrap used, a great deal of which is sold in Europe.

" *Casting.*—The casting is not so well done as in Europe, probably because the men are not so well trained owing to the want of apprentices. The furnaces are mostly of the round type, the fuel is anthracite, and the metal is frequently poured through a funnel with several holes in the bottom, which is put on the top of the ingot moulds. The rods are cast in split or solid moulds, the latter being fitted with a plunger at the bottom, by which the rods are pushed up as soon as they have set. Owing to the casting being less carefully done than here it is necessary to clean the surface, which is either done by planing the ingots or by scraping (scalping) the ingots after breaking down.

" *Rolling.*—The rolls are generally speeded up, and run about 50 per cent. quicker than here, beginning with ten to twenty revolutions and finishing at forty-five to fifty revolutions. The rolls are kept fully at work, but this of course is only possible by having two or three more men at every pair of rolls than we have in this country.

" The annealing furnaces are all inflame oil furnaces, worked at 650° to 850° C. They are charged with a load of 20 to 30 cwt. on a tray, and a charge does not take more than from one hour to one and a half hours.

" There are a great many supplementary machines of modern construction. Gang-slitters, shearing machines fitted with automatic scrap cutting devices; pickling, brushing, and drying machines; overhead electric cranes, and everything that will substitute power for manual labour.

" *Wire-mills.*—Most of the wire-mills work exclusively with continuous machines with the exception of course of the bullblocks, and the rods are annealed in open cylindrical furnaces. Great attention is given to temper, of which five degrees are recognised: namely, very soft, soft, medium, half-hard, and hard."

In conclusion, Mr. Boeddicker said that as far as he had seen " all the American works are admirably planned and

admirably managed; that everywhere a great many improvements have been introduced, of which a great number are only advantageous where one can deal with large quantities. That we here in Europe are unable to adopt them, partly because the works are not large enough and partly because the orders on this side are on a smaller scale than in America, where everything is standardised much more than here. In his opinion it would be a great mistake to say that because England has not adopted new ideas as quickly as America, that England is behind. Every country and every industry develops according to special requirements, and if ever a consolidation of any of our metal industries should become an accomplished fact, greater standardisation in the different works would be possible, and it would be proved that the English metallurgist is quite as able and anxious to adopt up-to-date methods as our American friends."

A discussion followed the reading of Mr. Boeddicker's paper, in the course of which Mr. J. W. EARLE said : " On approaching most of these mills one is impressed with their situation, size, design, and adaptability for handling their freight. The most modern mills are built in separate sections, that is to say, one mill will be confined to making rolled brass and copper, another to seamless tubing, another to rod and wire, and so on according to their manufactures. Encircling these large buildings runs a railway track which serves to avoid cross traffic from one mill to another. So much for the outside of the mills. When one enters the interior one is struck with the height and width, also the large area of working room which admits of everything being kept in line and the facilities for the carriage of the material from one point to another.

" *Casting Shops.*—These are very similar to those in use in this country, except that the furnaces are placed somewhat nearer the centre of the shop and level with the floor. The flues run into a large stack which is placed midway between a given number of furnaces. The furnaces are of the ordinary square type in which crucibles of about 150 lbs. capacity are employed. The stock is of a high grade, both as regards

the copper and spelter, very little scrap being used. The output I have not before me, but it is considerably in excess of the practice in this country. In regard to the quality of the work, that, for some reason which I have not had the opportunity of investigating, is very rough. This I fancy is due to either the ingot moulds being roughly cast or insufficient attention being paid to them, or perhaps both.

" *Rolling-mills.*—These are generally of a much heavier type than those of this country. Originally, of course, exactly the same class of mill as some of our older mills was employed, but the evolution to meet the peculiar needs of the country and the conditions have brought about these heavier mills, which have everything on a larger scale right away down from the engine to the pickle boshes."

SECTION II.

ABSTRACTS OF PAPERS

RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

CONTENTS.

ORES AND MINERALS.

CONTENTS.

I.—OCCURRENCE.

Antimony in the Yukon.—D. D. Cairnes * describes the Wheaton River antimony deposits, Yukon Territory. These ores are the only ores of antimony yet discovered in the Yukon Territory, and their occurrence is limited to a single locality about 2 miles wide by 3 or 4 miles long. The deposits occur near the western edge of the Yukon plateau, not more than 5 miles from the typical mountains of the coast range, where the effects of erosion and uplift are strikingly in evidence. The district is sparsely forested, yet sufficient timber occurs for all mining purposes, while the climate is similar to that of many districts of British Columbia. The antimony deposits are of a rare type, and occur as fissure veins, chiefly in granites and andesites. They may be classed into ore-containing cavities, valuable chiefly or entirely for their antimony contents; gold-bearing ores, in which the stibnite is auriferous; and ores containing both antimony and silver. Another category consists of metasomatic replacements, but most of the deposits of antimony ore belong to the first three groups. Assays of samples of surface ore of the better class, containing considerable galena and grey copper, show that they often carry from 100 to 200 ounces of silver per ton. Carbon and Chieftain Hill ores rarely contain more than traces of gold. A typical analysis of ores found on the Porter claim showed 50 ounces of silver, 31 per cent. of lead, and 18·75 per cent. of antimony.

Chitina Valley Copper Deposits, Alaska.—The copper deposits of the Chitina Valley are described by E. Jacobs.† These deposits will be rendered available by the completion of the Copper River and North-Western Railway from Cordova. The deposits include copper, gold, realgar, and coal. In the Bonanza Mine the copper ores are chalcocite

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* *Journal of Canadian Mining Institute*, vol. xiii. p. 297.
† *Mines and Minerals*, December 1910, vol. xxxi. pp. 315–318.

and azurite. The chalcocite is in masses of solid ore up to 5 or 6 feet in thickness, in large irregular-shaped deposits and in stockworks in the limestone. Azurite appears on the surface of the chalcocite, and also as a lining for small vugs, but is present chiefly as thin veins forming a network in the limestone. The Bonanza is an exceedingly rich and unusual body of copper ore, and roughly approximate estimates have been published of the quantity of ore available. These place the quantity at 200,000 to 300,000 tons of ore ranging up as high as 50 per cent. copper.

Copper and Lead in Sweden.—Copper and lead ore * and some silver ore have been discovered in the Gunnarskoy district in Värmland, Sweden. An old silver mine at Tobal has been reclaimed, and will probably also be worked again. It is said that mining operations on a large scale are soon to be commenced by joint Swedish and German concerns.

Copper in Arizona.—The Vekol deposits in the Kaiser Grande mining district in Penal, County Arizona, are described by E. Higgins.† The range rises abruptly from the surrounding desert plain, its eastern face forming a bold fault-escarpment. A characteristic occurrence is the intrusion of an acidic porphyry in the form of dykes. This is known as the Vekol porphyry, and it is in these masses that the copper ore occurs. The exposed ore shows the effect of thorough oxidation and leaching, but as depth is gained the red oxide found earlier gives place to carbonates, while in one place sulphide ores occur.

Copper in Congo Free State.—The occurrence and native mining of copper in the Congo Free State are described by S. H. Ball ‡ and M. K. Shaler. The Katanga copper range is the most important. The deposits are situated in south-eastern Belgian Congo, about 11° S. of the equator, and not far north of the Rhodesian frontier. Up to date about 100 deposits are known, included within a belt extending 90 miles east from the Lufupa River, thence bending suddenly south-east, and reaching a point 110 miles away. They are situated in a plateau whose surface has been dissected into a region of rounded hills and rather steep-sided valleys. Elevations of the higher hills and the lower valleys are respectively 5300 and 4000 feet above sea-level. The copper-bearing strata are harder as a rule than the rocks of the surrounding country, and, in consequence, the ore deposits are usually located on hills. These hills, in contradistinction to the surrounding timbered country, are bare of trees and shrubs, and between them and the forests grow the misuka or mahohohobo bush, which is a most excellent copper-indicator. The ore bodies vary in size from comparatively small to mammoth ones, such as Kombove No. 2, reported to be 3000 feet long, and, so far as tested,

* *Engineering*, December 30, 1910, vol. xc. p. 892.
† *Engineering and Mining Journal*, 1911, vol. xci. p. 473.
‡ *Bulletin of the American Institute of Mining Engineers*, 1910, p. 260.

from 240 to 400 feet wide. It is said to contain 10,000,000 tons of 15 per cent. copper ore in each 100 feet of sinking. Other deposits are also described.

Copper in Cuba.—B. B. Lawrence * gives an account of the copper deposits mined by the Cuba Copper Company. The El Cobre Mine of that company dates back to 1544, when it was discovered by the Spaniards and worked by means of slave labour. At a later date an English company was formed, and the labour was performed by black slaves and Chinese, supervised by Cornish mine captains. When the mine was pumped out, numerous mahogany props, measuring up to 40 feet in length, were found, and, as they were perfectly preserved by the copper-sulphate waters, were used again after an interval of fifty years. The mines now possess modern machinery and equipment. The richest ore is sulphide, of highly siliceous nature, carrying 20 cents of gold and half an ounce of silver. It is very free from impurities. At the west end of the main Cobre veins is a small vein of zinc blende, chalcocite, and pyrite carrying 15 dollars in gold. The deposits are of vast extent, and a million tons of ore and 140,000 tons of copper have been shipped from the property since 1830. The Spanish-American Iron Company worked hæmatite deposits occurring twenty-six miles from Santiago de Cuba.

Copper Ores in Arizona.—E. Higgins † gives an account of the Copper Creek basin resources. The ores occur on the west slope of the Galiluro Mountains, in Arizona, and the ore bodies belong to the class of disseminated deposits. They are found mainly in masses of brecciated and altered diorite, carrying pyrite, chalcopyrite, and bornite. Secondary chalcocite is common in most of the ore bodies, and native copper occurs in sheets along the shear zones as well as in masses and grains. The ore bodies outcrop in well-defined masses, stained with iron and copper, and their shape is usually elliptical. The most southerly of the three known groups in the brecciated belt contains an ore body 100 feet long, and from 50 to 60 feet wide, together with a large body of milling ore, the total supply being estimated at 60,000 tons, carrying an average of 3·78 per cent. of copper, a trace of gold, and 8 ounces of silver per ton. Other deposits consist of the Old Reliable group, the Prince group, and the Globe and Giant Mines. At the Globe Mine secondary copper glance appears, and the shaft opened at the mine has developed 300,000 tons of commercial ore, well blocked out for mining. The work done in various tunnels and shafts on the property of the Copper Creek Mining Co., which embraces a number of these claims, represents a total of 410,000 tons of developed ore of an average grade of 3·25 per cent. copper, and about three times that amount of probable ore. The smeltery is in course of construction, and will consist of one 175-ton reverberatory furnace, one matting furnace of 75 tons capacity, and a converter. The reverberatory furnace is of the type used at Cananea, and will be equipped with burners for crude oil.

* *Journal of Canadian Mining Institute*, 1910, vol. xiii. p. 91.
† *Engineering and Mining Journal*, 1911, vol. xci. p. 270.

Copper Ores in Canada.—J. Douglas * describes early copper mining in the province of Quebec. The deposits described are those of Inverness, Leeds, and Harvey Hill. The cost of mining operations and of dressing the ore is given.

Gold and Silver Mines of Nevada.—A description is given by P. E. Van Saun † of the ores treated at the new mill at Nevada Wonder Mine, Churchill County, Nevada. The principal ores are hard, tough, oxidised quartz carrying a small percentage of high-grade sulphides of both gold and silver. The silver in the sulphides is mainly in the form of argentite and steelenite, together with some native silver. The gold is principally free, occurring in combination with sulphides, but is scattered in fine particles throughout the ore. The mines are situated on the Southern Pacific Railway, and are connected by a branch with the main line at Hazen. The principal shaft has been sunk to a depth of about 500 feet and connects with the main ore beds, which are known as the Wonder and Badger veins. It is intended ultimately to treat the product by the cyanide process, and the crushing mill will be driven throughout by electrical machinery.

Gold in Bolivia.—F. Glaizot ‡ describes the occurrence of gold in Bolivia. Most of the Bolivian mines are found on the slopes of the Cordilleras, on the uplands, where the folds of the strata are for the most part filled with veins of metal, of which a large variety occurs. For many years past gold and silver have been the principal sources of the metallurgical wealth of the country, which also produces notable quantities of wolfram, antimony, lead, zinc, and bismuth. The gold is found both in the form of alluvial deposits and in veins. The former are the most important. The placer workings of Tipuani are the most famous, having been worked by the Incas of old, and subsequently in 1562 by the Spaniards. More recently this region has been prospected by Bel. At present, however, only the deposits of the Rio Chuquiaguillo are worked. They are treated by hydraulic methods and by amalgamation, the residues being concentrated on a Ferraris table.

Gold in Canada.—F. Church § describes the various types of gold deposits occurring in Canada. The Klondyke placers are the principal producers. In the Le Roi and Centre Star Mines of the Rossland district the lodes are replacements, while in Nova Scotia the principal types of gold deposit are saddle reefs. The geological formations in which gold is found and the characteristics of the ores and veins are discussed.

Gold in French Guiana.—The occurrence of gold in French Guiana ‖ is discussed by A. F. J. Bordeaux. Alluvial gold was first

* *Journal of Canadian Mining Institute*, 1910, vol. xiii. p. 254.
† *Engineering and Mining Journal*, vol. xci. pp. 520–522.
‡ *Bulletin de la Société de l'Industrie Minérale*, 1910, vol. xiii. pp. 5–16.
§ *Engineering and Mining Journal*, 1910, vol. xci. p. 470.
‖ *Bulletin of American Institute of Mining Engineers*, November 1910, p. 889.

discovered in Guiana in 1852, and since that time numerous rich placers have been found. The annual production is now estimated at a value of about $100,000,000. The geological formation of French Guiana is not known in any detail; but the rocks are mostly pre-Cambrian, and consist of granitic gneiss, common granite, quartzite, and limonite. The gold occurs in quartz veins and boulders, disseminated in the laterite of the surface, along the seashore and the southern parts of the Manna and Maroni Rivers. As a rule the upper creeks running along the rich zones are better than the lower ones. The gold-dust from the upper Manna placers contains from 96 to 98 per cent. of pure gold. The conditions of mining are not easy, and there is much unlicensed prospecting and working. Dredging is employed with some success; but the occurrence of boulders and tree trunks and stumps militates against its extended employment. The conditions are described in detail, and the cost of labour and appliances given. Much gold undoubtedly exists, but circumstances are not favourable to its exploitation.

Gold in Nevada.—C. T. Rice * deals with the development of the goldfield mines of Nevada. The country rock consists of a series of Tertiary volcanoes laid down on top of a basement of Cambrian sediments, into which has been intruded an alaskite mass. The volcanic rocks consist of rhyolites, latite, dacites, and andesites, and through their mass there extends a crescent zone of fissuring with the horns of the crescent pointing to the south-west. It is along this crescent that the ore deposits occur. A body of copper-bearing sulphide ore is found in latite on the 800-feet level of the Polverde section. It is about 2 feet wide, and averages about 30 dollars of gold per ton. The Clermont ore on the 100-feet level also carries free gold, is low in copper, and amenable to cyanidation. One of the ore bodies on this level is 20 feet wide, and averages 100 dollars per ton, while richer ore bodies exist which carry as much as 800 dollars per ton. The theory as to the formation of the rich ore is discussed at some length, and there is no reason to suppose that these ores will not persist to as great depths as the Comstock, the main consideration being how the depth will affect the quantity rather than the grade. The ore bodies on the Florence goldfield rival those described, and appear to be more defined and to stand much nearer vertically. The bulk of the ore, however, is of the milling grade, averaging about 12 dollars per ton.

Gold in Nicaragua.—T. L. Carter † points out that while information is available as to mining districts in all parts of the world—America, Europe, Asia, Africa, and Australia—there is not one description of the mining possibilities of Nicaragua. Mining in Nicaragua was in operation when the Spanish conquerors penetrated into the interior and forced the natives to procure the precious metal for them. It is strange that the Spaniards did not find more gold, and work on a scale as extensive as in

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* *Engineering and Mining Journal*, vol. xci. p. 119.
† *Bulletin of the American Institute of Mining Engineers*, 1910, p. 965.

'olombia and other parts of South America. Probably in Nicaragua the
ndians covered up most of the rich prospects to hide them from the
onquerors, and as the Spanish were not prospectors, they spent little
ime looking for gold. About 1888 the first discoveries of gold were
nade in eastern Nicaragua, and on the Atlantic coast. The placers did
ot last long, and were soon abandoned for vein-mining. No attempt on
working scale has been made at dredging, the indications not being
avourable. A promising field for investigation is furnished by the black
ands on the coast, especially from Walpasixa along Cape Gracias.
The future of gold mining in Nicaragua depends, however, on the develop-
ment of the veins.

Gold in Northern Madagascar.—A. Merle * describes the
auriferous deposits of northern Madagascar. They were discovered in
1905, and are situated 150 kilometres to the south of the town of
Antsirane, at the foot of the sandy cliffs of Andavakoera The auriferous
deposits are found in a band of sandy schists which gradually pass,
towards the south, into gneiss and mica-schist. The gold is contained in
veins of quartz which traverse this band, in association with gold-
bearing barytine. Iron and copper pyrites, galena, and blende are also
found associated with the quartz, and the gold occurs either free or as
a sulphide, and is distributed throughout the quartz matrix in needles
and grains. A considerable amount of silver is also combined with the
gold. The deposits are extensive, and afford employment to over 4000
workpeople. The annual output is about 1,277,890 grammes, of the
value of 3,066,936 francs.

Gold Mining on the Rand.—Details as to gold mining operations
at the Rand gold mines are given by R. Peele.† He gives a description
of the principal reefs worked, their persistence in length and depth, the
cost of deep shaft-sinking, and the relative merits of double stage
hoisting, together with notes on the handling of ore underground, native
labour, the support and sand-filling of empty stopes, and the elevation
of tailings by means of wheels.

Influence of Manganese on Enrichment of Gold Deposits.—
The agency of manganese in the superficial alteration and secondary
enrichment of the gold deposits of the United States is discussed at
length by W. H. Emmons,‡ who considers the subject under the following
heads :—(1) The salts contained in the waters of gold and silver mines in
non-calcareous rocks ; (2) chemical experiments in the solution and
deposition of gold ; (3) experiments on various salts and on the amount
of chlorine necessary for the solution of gold in the presence of man-
ganese compounds ; (4) the transference of gold solutions ; and (5) the
actual conditions obtaining in gold districts in the United States.

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* *Annales des Mines*, 1910, vol. xvii. p. 470.
† *Engineering and Mining Journal*, 1911, vol. xci. p. 320–322.
‡ *Bulletin of the American Institute of Mining Engineers*, 1910, p. 767.

Previous investigations and the present experiments show that ferric iron, cupric copper, and manganitic manganese are present in many mineral waters, and under certain conditions will liberate chlorine from sodium chloride in acid solutions. As nascent chloride dissolves gold, each of these compounds will thus release chloride at high temperatures, and at low temperatures in concentrated solutions. Manganitic compounds (supplied by pyrolusite, &c.) liberate chlorine very readily. It should be expected, then, that those auriferous deposits, the gangues of which contain manganese, would show the effects of the solution and migration of gold more clearly than non-manganiferous ores. The gold thus dissolved is precipitated by ferrous sulphate. It is, therefore, natural to suppose that gold in such solutions could not migrate far through rocks containing pyrite, since it would be quickly precipitated by the ferrous sulphate produced through the action of air, oxidising waters, or the gold solution itself, upon the pyrite. But the dioxide and higher oxides of manganese react immediately upon ferrous sulphate, converting it to ferric sulphate, which is not a precipitant of gold. Consequently, manganese is not only favourable to the solution of gold in cold, dilute mineral waters, but it also inhibits the precipitating action of ferrous salts, and thus permits the gold to travel farther before final deposition.

Those deposits in the United States in which a secondary enrichment in gold is believed to have taken place are, almost without exception, manganiferous. Since secondary enrichment is produced by the downward migration, instead of the superficial removal and accumulation, of the gold, it should follow that both gold-placers and outcrops rich in gold would be found more extensively in connection with non-manganiferous deposits ; and this inference is believed to be confirmed by field observations.

The problem is a difficult one, and some of the numerous and complex data bearing upon it are collated and discussed, but they tend to prove the assumptions made to be substantially correct, and to show that the presence of manganese plays a notable part in the enrichment of gold deposits.

Lead Ores in Algeria.—The most important deposits of lead in the province of Oran are at Traras, and on the Tlemcen Hills.* These regions are traversed by veins, of which galena is the principal mineral. It is argentiferous, and carries up to 1000 grammes per ton. The amount of the deposits is not large. Other deposits occur in the department of Constantine. Details as to the cost of mining, local wages, and transport charges are given.

Lead Ores in Missouri.—The growth of lead mining in south-east Missouri is discussed by H. A. Wheeler.† The district has been productive for two centuries, which constitutes a unique record. The output was formerly derived from shallow deposits which occurred in chunks and large crystals, which, when hand-cleaned, assayed to about 80 per

* *Annales des Mines*, 1910, vol. xvii. p. 24.
† *Engineering and Mining Journal*, vol. xci. p. 129.

·ent. Since 1870 large bodies of disseminated ore have been worked, and
·f late years a number of companies are engaged in mining operations,
·nd large mills of 1200 to 4000 tons capacity have been put down.

Leadville Ore Deposits and their Genesis.—The usually
·ccepted theories of the genesis of the Leadville ore deposits, Colorado,
·re challenged by M. Boehmer,* who considers them fallacious, and
·ropounds an alternative theory. Recent developments have shown
·hat the Leadville deposits have their origin in depth through the
·hannels of fissure veins and dykes of eruptive rock. It seems reasonable,
·herefore, to assert that the proximity of the gold-belt to the original
·issures and dykes explains the existence of gold in the veins of that
·articular area. Gold would naturally be precipitated first ; and thus it
·did not find its way, except in a solitary instance, to the westerly
·portion of the district. The most recent discoveries in Leadville throw
·much new light upon the difficult problem of the genesis of ore bodies
·lsewhere.

Metalliferous Deposits on the Red Sea.—The metalliferous
·veins at Gebel Roussas, on the Red Sea, are briefly described by R.
·Fourtau.† The two mounds situated at 5 kilometres from the shore
·consist of gravels and clays, with veins of carbonates, in which zinc and
·lead are present in considerable quantity. Large amygdaloidal masses of
·galena occur at one level, thickly encrusted with cerrusite. Blende is
·not present.

Mineral Resources of the Japanese Empire.—A review of the
·Japanese mineral industries is given by A. Selwyn Brown.‡ Silver and
·lead deposits are found in many localities, but there are only a few
·important mines yielding these metals, their total production being about
·4,000,000 ounces of silver and 3000 tons of lead per annum. Ores con-
·taining zinc blende occur throughout the empire, but many of the richest
·deposits are unworked on account of the lack of efficient transportation
·facilities. The total production of zinc ore in Japan is about 20,000
·tons per annum.

Ores of antimony, manganese, and tin are also mined with more or
less success in several localities.

Japanese mines are generally well worked and well equipped with
machinery. Good and efficient metallurgical works exist for the treat-
ment of metallic ores close to the mines, and there is every reason for the
belief that the remarkable progress made in the development of the
mineral resources during the past decade will be continued.

Mineral Wealth of Spain.—M. Iborra J. Mas§ contributes an
exhaustive summary of the chief minerals found in Spain, as ascertained
by the labours of the Spanish Natural History Society. The classifica-

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* *Bulletin of the American Institute of Mining Engineers*, 1910, p. 119.
† *Comptes Rendus*, 1911, vol. clii. p. 143.
‡ *Engineering Magazine*, January 1911, vol. xl. pp. 568-583.
§ *Revista Minera*, 1910, vol. lxi. p. 626.

tion adopted is that propounded by Groth and universally accepted, and the minerals are grouped according as they fall under the various categories.

Mount Morgan Ore Deposits.—Some notes on the Mount Morgan ore deposits, as they appear now, are given by J. B. Wilson.* The early history of the mine is given, in which it is stated that the deposit was discovered in 1882, and up to 1903 was known only as a gold mine; but in that year a copper-bearing body was discovered when prospecting the lower levels of the mine, this body being estimated to contain 2,800,000 tons of ore, averaging 3·25 per cent. copper and 5 dwts. gold. Up to December 1907 the company treated 2,110,634 tons of oxidised ore by chlorination, 926,284 tons of sulphide ore by chlorination, and 181,191 tons copper-gold ore by smelting.

The geology of the district is discussed, and the theories to explain the origin of the deposits are given and discussed.

A description of the ore body is given. The open cut is 360 feet below the original summit of the hill, and has an area of 11 acres. The amount of mineralisation varies from siliceous ores containing 80 per cent. silica down to basic ores carrying only 6 per cent. silica, the average of the whole ore body being 55–60 per cent. silica. A list of minerals found at Mount Morgan includes gold, iron and copper pyrites forming the payable ore bodies, traces of zinc blende, tellurium, and selenium; tin oxide, only found in minute quantities in oxidised ores, and gypsum, both fibrous and crystalline, found on the edges of the dykes.

Platinum in British Columbia.—The platinum deposits of the Tulameen district in British Columbia are described by C. Camsell.† The mining of platinum in this region dates from 1885, and in the early days was purchaseable at about 2s. an ounce. It was regarded by the miners as detrimental rather than otherwise, and usually was not even saved in the "clean-up" when mining gold, which had been discovered as far back as 1858. Much of the gold and platinum found in the Tulameen district is coarse, and has the rough unworn surface characteristic of nuggets which have not travelled far from their original source. Much of the gold is found embedded in quartz, while the platinum is often associated with pyroxene, olivine, or chromite, and the source whence they are derived is probably certain old beds of sandstone and conglomerate which outcrop on Collins Gulch, Blair Creek, and the northern face of Jackson Mountain. The platinum rarely occurs in large nuggets comparable with those recorded in the case of gold, and seldom exceeds half an ounce. Most of the platinum occurs in small grains or pellets which can be separated into two parts, non-magnetic and magnetic, the nonmagnetic forming the greater proportion of the total. Analysis shows a sample separated from the associated grains of foreign matter to consist of the following minerals :—

* *Bulletin of the Institution of Mining and Metallurgy*, November 1910, No. 74.
† *Journal of the Canadian Mining Institute*, 1910, vol. xiii. p. 309.

								Per Cent.
Platinum .	.	.	.	.	.	.	.	72·07
Palladium	.	.	.	.	.	.	.	0·19
Rhodium	.	.	.	.	.	.	.	2·57
Iridium .	.	.	.	.	.	.	.	1·14
Copper .	.	.	.	.	.	.	.	3·39
Iron .	.	.	.	.	.	.	.	8·59
Osmiridium	.	.	.	.	.	.	.	10·51
Gangue .	.	.	.	.	.	.	.	1·69

Prior to 1905 no data relative to the statistics of production in British Columbia are available, but the output is estimated at about 20,000 ounces. Much of the placer mining is undertaken by Chinese. The early methods of separating the platinum from the associated minerals were crude in the extreme, and, as no systematic operations have been yet undertaken, the methods of separation are still primitive.

Quicksilver in Texas.—The production of quicksilver in Texas is noted by W. B. Phillips, * who gives the output for 1910 as 3382 flasks. The ores are chiefly cinnabar, but in some localities native metal is found together with rare minerals bearing mercury. The increasing scarcity of fuel in the region where mercury is found has drawn attention to the use of local coal in gas-producers. An abundant supply exists, and as the wood now being used has to be hauled over 30 miles, the employment of coal should effect economy.

Silver in Bolivia.—A description of the celebrated silver mines of Potosi is given by F. Glaziot. † These deposits are nearly exhausted, and silver mining in this region has largely given way to the mining of tin. Besides silver and tin, veins of argentiferous galena occur, which it has become no longer profitable to mine, but which in former days were exploited by the Spaniards. The occurrence of bismuth and of tin in Bolivia is also noted.

Silver in Ontario.—The calculation as to the probable number of productive veins in the Cobalt district is given by G. R. Mickle,‡ and he compares them with those of the most productive silver districts in Europe, namely, Annaberg and Schneeberg.

Silver-Lead in Staffordshire.—Deposits of silver-lead § have been found in the village of Butterton, near Leek, Staffordshire. The new seam lies close to the surface. Three substantial consignments have been already disposed of and several tons await dressing. The lead contains a good percentage of silver. The neighbourhood was formerly famous for its lead mines.

Tin in the Belgian Congo.—The tin deposits of the Belgian Congo are described by S. H. Ball ‖ and M. K. Shaler. While cassiterite

* *Engineering and Mining Journal*, 1910, vol. xci. p. 419.
† *Bulletin de la Société de l'Industrie Minérale*, 1910, vol. xiii. p. 17.
‡ *Journal of Canadian Mining Institute*, 1910, vol. xiii. p. 325.
§ *Engineer*, March 10, 1911, vol. cxi. p. 247.
‖ *Bulletin of the American Institute of Mining Engineers*, 1910, p. 273.

has been reported from many localities, it is only in the Katanga that deposits rich enough to exploit in the future have been found. The tin belt of the Katanga is situated on the west slope of the rugged Bia Mountains. The rock is a biotite granite, which intrudes mica-schists, slates, and quartzites, carrying tourmaline, and is considered to be of Silurian age. The tin deposits are of three kinds : quartz-muscovite-cassiterite veins, residual deposits from these, and placers derived directly from the other two sorts of deposits. The veins are for the most part situated in the sedimentary rocks near the granite. They are vertical, and occur in two sets, one quite regular in values and the other sometimes richer but less constant. The veins are from 300 to 4000 feet long. Cassiterite occurs in good and often very large crystals, imbedded in quartz, and is frequently more abundant near the borders of the veins. The residual deposits are derived from the breakdown of these veins. The tin-bearing layer averages 2 feet in thickness and carries a mean average of 1 per cent. of tin. These deposits, discovered in 1903, are estimated to contain 20,000 tons of tin of excellent quality. On the ground, early in 1906, some 8 tons of tin were smelted.

Tin in Bolivia.—F. Glaziot * contributes a special study of the tin mines of the department of La Paz and Oruro. The deposits of tin occur at the counterscarps of the Royal Cordilleras at a height of 4000 metres above sea-level. They are of three descriptions—fracture veins, contact deposits, and alluvial deposits, but the latter are exceptional and do not repay working. The sources most frequently encountered are the vein ores, which are generally regular and traceable for a considerable distance. Indeed they often form veritable stockwork in the schists or in the quartzite of which the native rock is composed. The thickness of the tin veins varies from half a metre to 15 metres, and are reported to contain as much as 25 metres. They are frequently filled with sedimentary detri-tus, which has been transported *in situ* at the moment of faulting ; it frequently encloses chalk. The cassiterite is found in crystals of varying sizes, and often forming concretions which may attain half a metre in thickness. It is often intimately associated with iron pyrites and with other minerals such as galena, blende, wolfram, chalcopyrite, native bismuth, and chlorides and sulphides of silver. Their general appearance is described at length, together with the methods of working, after which the author gives details respecting the individual deposits of Huani-Potosi, Milluni, Quimsa-Cruz, and similar deposits elsewhere. Some of the methods of mining are primitive, but may be divided into two categories : (1) The mineral being treated by rudimentary appliances without previous mechanical preparation ; and (2) in concentration works. A list of the works, some of which possess modern appliances and machinery of a most efficient description, is given, together with a table showing the production of tin in Bolivia during the last twelve years. In 1908, the last year for which returns are given, the production amounted to 18,735 tons, at an average price of 29 cents per lb.

* *Bulletin de la Société de l'Industrie Minérale*, 1910, vol. xiii. p. 22.

Tin Mining near El Paso.—The occurrence of tin ores and their method of mining on the eastern slopes of Mount Franklin, about ten miles north of El Paso, Texas, are described by W. E. Koch.* The tin ore bodies are found in the granite, and consist of veins, stockworks, and zones of impregnation. The ore is cassiterite. Water is rather scarce, and as tin ore is especially apt to slime, Sutton and Steele dry tables are used. The concentrate assays about 60 per cent. of tin, but the tin is so pure that it scarcely needs refining, as the ores are free from arsenic, copper, and other impurities, except a little iron, which is easily kept out.

Tungsten Ore in Washington.—An account is given of the deposits of tungsten ore in Washington by A. Wolf.† Boulder County is the country's chief producer, having an output of 3000 to 4000 tons of concentrates a year. In the Germania camp, the crude ore in the lower levels contains 3 to 4 per cent. tungstic acid with a little pyrite, while in the upper levels the percentage is 4 to 6 with much pyrite. The Tungsten King property contains ore running 6 to 8 per cent., but about 50 per cent. of this is lost by imperfect treatment.

The concentration of tungsten ore in Stevens County is accomplished with less difficulty than in Colorado, as the tungsten is of greater solidity and higher percentage ; it occurs in chunks of various sizes ; crushing the ore to $\frac{3}{16}$ size makes possible a high saving and produces little slime.

The general markets demand tungsten mineral running 60 per cent. tungstic acid, and the desire of many millmen to raise the concentrate to 70–72 per cent. can only be realised at the expense of a middle product, which by lower concentration can be avoided.

The general experience has been that the best results are obtained in an effort to make a 62 per cent. product.

Valuation of Ores.—The methods for the valuation of metallic ores on the basis of their analysis are reviewed by A. Rzehulka ‡ in a series of articles, formulæ being given for representing the value per ton, taking into account the analytical results and the loss of metal during the operations of extraction.

Value of Gold Quartz.—F. Laur § gives a formula for the calculation of the value of auriferous quartz which he proposes as a basis for sale. It is

$$P = (T - 7) \times 3.35 - F$$

when P = price per ton of the mineral in francs ; T the grammes of gold per ton ; 7, an arbitrary figure representing the normal loss of the precious metal ; 3·35, the average price in francs per gramme of gold ; and F the

* *Engineering and Mining Journal*, vol. xci. p. 168.
† *Mines and Minerals*, December 1910, vol. xxxi. pp. 307–308.
‡ *Zeitschrift für angewandte Chemie*, 1910, vol. xxiii. pp. 481, 1970, 2203 ; 1911, vol. xxiv. p. 444.
§ *Revista Minera*, 1910, vol. lxi. p. 577.

cost of extraction estimated at 30 francs per ton by the cyanide process, and a little more by the lead cupellation process.

Zinc-Lead Ores in Algeria.—Sergère.* gives analyses of samples of zinc-lead ores from Ouled Sellem and Bou Aoun. Some of the Ouled ores contain as much as 59·28 per cent. of zinc, while those from Bou Aoun range from 31·62 to 44·55 per cent. A number of samples were also analysed at the Oran laboratory by Ponselet, including some Calam mines derived from Kalâa, containing from 47 to 52 per cent. of zinc and galena, containing 55·08 per cent. of lead. Analyses of some argentiferous lead ores are also given.

Zinc Ores of Millau.—The zinc ores of Millau (Aveyron) are briefly described by A. Salz.† The deposits form irregularly horizontal sheets in the Lower Lias, and consist of calamine, associated with baryte and with galena. The percentage of zinc is from 30 to 35, diminishing to 22 per cent. at a distance from the fault. About 100 tons of mineral containing 30 to 35 per cent. of zinc have been extracted at Vezouillac, but the extent of the deposits is very uncertain.

Zinc Ores of Leadville, Colorado.—The utilisation of waste ores at Leadville is described by F. Guiterman.‡ The ores are residues from lead blast-furnace smelting, and it is only recently that their value for extraction of zinc has been recognised. They were believed to have been zinc carbonate ores, and the assays made were only for the purpose of determining their value as fluxing material for the lead smelters, the disappointing results obtained leading to their rejection as ores of commercial utility. As a matter of fact, the ores consisted of crystallised and crystalline masses and almost pure silicates (calamine), and the occurrence has emphasised the need for a thorough knowledge of the mineralogical character of the ore bodies of a mine, regardless merely of their gold, silver, lead, or copper contents.

II.—*MECHANICAL PREPARATION*.

Chilian Mills in Russia.—A description of the standard type of Chilian mills and milling methods as used in Russia, and some notes on an improved type of Chilian mill and plant are given by H. C. Bayldon.§ The slow-running Chilian mill is almost universally used in Russia to crush ores as a preliminary to amalgamation. It has gradually evolved from the practice of crushing ores by spreading on main thoroughfares for carts and other vehicles to pass over.

* *Annales des Mines*, 1910, vol. xvii. p. 529.
† *Revue des Métaux et Alliages*, 1910, vol. iii. p. 130.
‡ *Engineering and Mining Journal*, vol. xci. p. 171.
§ *Bulletin of the Institution of Mining and Metallurgy*, December 1910, No. 75.

The following are particulars of some typical mills crushing ore very similar in hardness and general character :—

	Mill No. 1.	Mill No. 2.	Mill No. 3.	Mill No. 4.	Mill No. 5.
Number of Chilian mills in plant	6	4	6	4	6
Number of runners per mill	2	2	2	2	2
Diameter of pan across bottom	7 ft. 6 in.	8 ft. 9 in.	8 ft. 2 in.	10 ft. 6 in.	9 ft. 4 in.
Distance between centres of runners	6 ft. 0 in.	6 ft. 9 in.	6 ft. 6 in.	8 ft. 3 in.	7 ft. 6 in.
Width of face of runner	10 in.	10 in.	$10\frac{1}{2}$ in.	10 in.	12 in.
Diameter of runner	5 ft. 6 in.	5 ft. 6 in.	6 ft. 6 in.	5 ft. 6 in.	6 ft. 6 in.
Weight of runner, lbs.	5400	5400	5400	5400	10,800
Revolutions of mill per minute	12	14	13·5	12	11
Mean travel of runner per minute	226 ft.	297 ft.	275·6 ft.	311 ft.	260 ft.
Height of discharge	10 in.	10 in.	$9\frac{3}{4}$ in.	$9\frac{1}{2}$ in.	8 in.
Screen used	1 mm. slotted	1 mm. slotted	$\frac{1}{4}$ to $\frac{1}{8}$ in. punched	1 mm. slotted	$\frac{1}{2}$ mm. slotted
Water to ore ratio, by weight	10 : 1	6·5 : 1	7 : 1	13 : 1	...
Duty per 24 hours, tons	16	26	20	19	24
Amalgam collected—	Per Cent.	Per Cent.	Per Cent.	Per Cent.	
From mills	86	81	83	85	...
„ plates	13	18	16	15	...
„ sundry sources	1	1	1	...	...

Sizing tests of the tailings from some of these mills resulted as follows :—

1 Millimetre Screen.	No. 1 Mill.	No. 2 Mill.	No. 3 Mill.	No. 4 Mill.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
+30	0·2	0·4	0·2	0·1
+60	2·41	14·84	3·2	1·3
+100	14·72	22·06	12·80	11·0
−100	82·67	62·70	84·80	87·6

The mean travel of the runners seldom exceeds 300 feet per minute, and the depth of the water above the ore is comparatively high.

The product is very fine and of uniform, even grade. The main object in view is to crush the ore very fine and to obtain the highest possible percentage of gold by amalgamation and from the pan itself. The capacity of the mills has been increased either by increasing the diameter and weight of runners or by increasing the number of runners from two to three. The latter would appear to be the better practice, but this type of mill has not become popular. With regard to the wear of tyres and

dies, the average weights of these parts when worn out and discarded are 10 to 15 per cent. of the original weight for tyres and 36 to 45 per cent. for dies.

Actual figures for No. 2 mill are as follows :—

Mill Spare.	Material.	Ore Crushed with Spare.	Weight of Spare when New.	Weight of Spare when Discarded.	Net Wear of Iron per Ton Crushed.	Percentage of Weight Discarded.	Cost of Spare.	Cost per Ton Crushed.
		Tons.	Lbs.	Lbs.	Lbs.		£	d.
Pairs of tyres .	Cast steel	8,910	7,873	1,083	0·762	13·7	65·62	1·77
Set of dies .	Cast steel	6,718	5,092	2,203	0·430	43·2	41·68	1·49
Totals and Averages }	...	7,314	12,965	3,286	1·192	25·35	107·30	3·26

Inside plate amalgamation is the standard practice, wash-ups are made every twenty-four hours, six to eight pounds of mercury being added to the mill at intervals during the day, two to three pounds of this being introduced an hour before the wash-up. The outside plates are run hard and kept under locked covers ; these are thoroughly dressed only once a month.

In the notes given on an improved type of Chilian mill, the chief features are connected with the mill building itself, the automatic belt feeder, and the improved Chilian mill. An overhead belt-feeder, operated either by the mills themselves or by independent mechanical means, has proved very satisfactory. This feeder is so arranged that the amount of ore delivered is increased or decreased as required. The new type of mill as designed by the author has a pan which is narrow at the grinding track, but the width is rapidly increased by sloping sides. The clean-up is made through an opening 24 inches in width closed by an iron slide at the back of the mill.

The diameter of the pan is 10 feet 3 inches, and the speed of the mill 14 to 16 revolutions per minute. The diameter of the runner is 72 inches and the width of the face 12 inches. The weight of the runner is 10,000 pounds, the weight of tyres alone being 6040 pounds. The size of the discharge opening is 44 × 8 inches. The life of the slotted screen is about 1200 tons of ore, and the capacity of the mill 42 tons per twenty-four hours.

The results of various tests are given with a summary of observations, and the author is of the opinion that, if the same amount of thought and attention were devoted to the development of the capacity of this type of Chilian mill as has been devoted to the heavy stamp-tube mill combination in South Africa, it would prove a serious rival and give a product nearer to the ideal aimed at on that goldfield.

Concentration of Platiniferous Copper Ores at Wyoming.—
An account is given of the nature, occurrence, methods of concentration,
assay, and treatment of the platiniferous copper ores * of the Rambler
Mine, Wyoming. Up to the date of the actual discovery of the platinum
metals in these deposits in 1901, nearly 4000 tons of copper ore, con-
taining 25 to 30 per cent. copper, had been shipped from the mine. The
first tests showed that various copper minerals carried from 0·1 to 0·7
ounce of platinum per ton, while a quantity of covellite ore carried from
0·4 to 1·4 ounce per ton, this platinum occurring as sperrylite (PtAs₂).
Later investigations gave evidence of the presence in considerable
quantities of other members of the platinum group of metals. A small
matting furnace was tried for the treatment of the ore, but this proved
unsuccessful, probably owing to the presence of large quantities of decom-
posed diorite. The problem of treatment for this ore is complicated by
the fact that the copper exists in a large variety of minerals, including
native copper, sulphides, carbonates, oxides, chloride, sulphate, and
silicate. The following table shows the distribution of precious metals
in the ore :—

Sample.	Value per Ton.	
	Precious Metals.	Copper.
	$	$
High-grade platinum, circular drift	36	3.28
Hard talc, N.W. drift	12	2.75
Sulphide, black drift	26	1.45
Talc, black drift	20	5.88
Talc, covellite drift	32	12.34
Black material, black drift	88	4.65
High-grade platinum opposite talc contact	100	75.00
White talc, at contact	26	5.75
Covellite, covellite drift	80	59.00
Brown talc, at contact	12	4.90
Precipitate above talc, covellite drift	116	68.60
General sample, stope level	26	16.40
Low grade, second level	12	2.00

As a result of experiments carried out in 1906, it was found that when
the ore was crushed to 2 millimetres and concentrated on a Wilfley table,
about one-half the platinum was obtained in the concentrate. The test
showed that the precious metals occurred in a very finely divided state.
An experimental mill has been erected, and the equipment consists of
crusher, rolls, trommels, classifier, Wilfley tables and canvas tables.
The following table gives results obtained in a test carried out in
June 1910 :—

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* *Metallurgical and Chemical Engineering*, February 1911, vol. ix. pp. 75–78.

Sample.	Ounces per Ton.						Cu. per Cent.
	Total Platinum Metals.	Au.	Pt.	Ag. and Pd.	Ir.	Ir., Os., and Rh.	
Platinum metal concentrate (table No. 1) . . .	28·00	4·66	11·82	11·08	0·08	0·36	23·1
Copper concentrate (table No. 1)	1·86	trace	0·06	1·26	trace	...	7·2
Platinum metal concentrate (table No. 2) . . .	17·68	2·36	4·86	10·36	0·10	trace	22·4
Copper concentrate (table No. 2)	2·40	trace	0·14	1·76	trace	...	12·6
Platinum metal concentrate (table No. 3) . . .	6·92	6·92	7·28	11·22	13·00	34·08	23·4

The general method of averaging the above materials are given. The figures do not represent direct weights of the metals indicated, but are calculated from differences in the weights of the buttons after successive partings with different acid solvents which are supposed to extract certain metals from the buttons.

Probably the best method of treatment for the Rambler ores would consist of direct smelting of the high-grade copper ore, producing a matte subsequently to be blown to blister copper. Concentration of the low-grade copper ore (2 per cent.) recovering a high-grade precious metal concentrate which could be refined chemically and a copper concentrate which could be smelted, blowing resulting matte to blister copper. The copper could be refined electrolytically and anode mud treated chemically. The copper carbonate and oxide ores could be leached with acid mine water.

Crushing at Cyanide Plants.—Crushing practice at cyanide plants is described by M. R. Lamb,[*] who points out that the recent growth of a sentiment among cyanide-plant designers against the use of gravity stamps for crushing previous to cyaniding may be said to date from the perfection of the rubbed tube-mill liner and of the tall air-agitation tank. There is at present a choice among three machines to replace gravity stamps in cases where neither concentration nor amalgamation is necessary. A simple crushing and grinding plant would consist of breaker, ball-tube mill, classifier, and pebble-tube mill, in which attendance and skill requirements would be reduced to a minimum. If rolls are preferred to the ball-tube mill, their substitution does not affect the other machines. If fuel is advantageously cheap, the plant will consist of crusher, steam stamp, classifier, and tube-mills. For small plants, or with unskilled labour, the slow Chilian mill has advantages. In either case, there is no work for the gravity stamp which cannot be done better by either of the other coarse crushers. The entire mechanics of the cyanide process have changed radically within a short period, but a doubt is

expressed whether the South African tendency to use heavier stamps will ultimately prove successful in comparison with present-day American practice.

Double-Stage Crushing.—Recent experiments carried out in South Africa by E. H. Johnson * have shown a remarkable performance in double-stage crushing. By first separating the fine ore from the stamp feed and delivering it direct to the tube-mill, he has obtained from ten stamps and one tube-mill a duty of 26·1 tons per stamp in twenty-four hours, and a final pulp containing 0·5 per cent. remaining on a 90-mesh sieve. Compared with single-stage crushing by stamps and fine screens, the above combination shows an increase of 32 per cent. in horse-power efficiency and 31 per cent. in grinding efficiency. This indicates possibilities for the tube-mill which have not yet been fully appreciated, and which will tend to place double-stage crushing on a firmer basis than ever.

The tube-mill, as a fine comminuter, is practically sure of its position in any system of stage reduction.

Differences of opinion exist regarding the value of stamps as coarse crushers, some metallurgists believing that rolls and Chilian mills would serve the purpose better.

Electrostatic Ore Concentration.—A paper on the applications of the electrostatic separation to ore dressing by F. S. MacGregor,† was read before the Chicago meeting of the American Electrochemical Society. Previous failures in the commercial application of electrostatic separation were due, according to the author, to a lack of proper means of continuous electrification and a want of a machine and system of treatment designed to meet the requirements of modern mill operation.

The Huff separators are illustrated and described, and various results obtained in practice are given, of which the following are examples :—

Material.	Product.	Copper per Cent.	Iron per Cent.	Lead per Cent.	Zinc per Cent.	Silica per Cent.	Gold, Oz.	Silver, Oz.
Low-grade chalcopyrite in quartz.	Original.	2·56	17·8	...	...	...	0·01	2·6
	Concentrate.	5·63	37·0	...	...	...	0·02	5·5
	Tail.	0·10	2·0	...	...	...	trace	0·4
Pyrite and chalcopyrite in various gangues.	Original.	6·37	25·0	...	...	...	...	...
	Concentrate.	9·33	36·3	...	...	...	...	...
	Tail.	0·14	1·9	...	...	...	...	...
Chalcopyrite and bornite in garnet.	Original.	3·60	18·6	...	...	32·3	...	...
	Concentrate.	19·10	25·7	...	...	14·4	...	...
	Tail.	0·34	17·6	...	...	36·7	...	...
Zinc, iron, and silver ore.	Original.	2·61	23·8	13·9	19·4	...	...	52·8
	Concentrate.	3·33	30·7	16·4	6·4	..	...	69·0
	Tail.	0·91	3·4	2·7	51·8	...	...	4·6

* *Metallurgical and Chemical Engineering*, February 1911, vol. ix. p. 60.
† *Ibid.*, November 1910, vol. viii. pp. 636–637.

Magnetic Separation of Zinc Ores.—In an article on zinc ore dressing, H. C. Parmelee * points out that the presence of much iron sulphite in zinciferous ores necessitates the adoption of different treatment from other ores, because wet dressing is insufficient on account of the slight difference in specific gravity between blende about 4 and pyrite about 5. Magnetic separation of blende and pyrite may be accomplished without preliminary roasting by the use of high intensity magnetic separators of the Wetherill type, the zinc mineral being lifted out of the mass. The more usual practice, however, is to give the mineral a magnetic or "flash" roast, rendering the iron magnetic, after which it is separated from the mass by separators of the low-intensity type, such as the Dings. In the roasting either magnetic sulphide (F_3S_4) or magnetic oxide (Fe_3O_4) may be produced, and experiments by G. M. Gouyard have shown that a better separation from galena and blende is obtained when the ore is roasted to magnetic sulphide only. Further, the roasting to magnetic sulphide is a simpler procedure than roasting to magnetic oxide, the latter usually requiring the addition of carbonaceous material to reduce ferric oxide to magnetic oxide. Siderite often occurs in zinc-lead-iron ores, and in the calcination process it is converted into magnetic oxide under much the same conditions which convert pyrite into magnetic sulphide.

Less time and slightly higher temperature are required for the conversion of siderite than of pyrite, but an ore containing both may be treated successfully, although the same degree of conversion of both minerals cannot be obtained.

Ore properly roasted for magnetic separation will be recognised by its uniform black colour and the absence of any reddish tinge. Blende will be covered by a thin layer of oxide.

The mill of the Wilson Mining Company, Colorado, is treating a mixed zinc-lead-iron sulphide with some siderite in a siliceous gangue, the average composition being silica, 11 per cent.; iron, 24 per cent.; lead, 10 per cent.; zinc, 15 per cent.; lime, 4 per cent.; sulphur, 36 per cent.

The mill has a capacity of 125 tons per day, and after crushing the ore is elevated to a dryer of novel construction, designed by O. H. Fairchild. This dryer consists of a vertical brick chamber about 20 feet high and 5 feet by 8 feet in its other dimensions.

Within the chamber are two sets of pans, so arranged and operated that each set alternately dumps its contents on to the other. As the pans of one set are staggered vertically with reference to those of the other, the ore fed on to the uppermost pan makes its progress through the dryer by a series of intermittent discharges from pan to pan. This exposes new surfaces of ore to the hot gases ascending from the fire-box in the base of the chamber, and thus effects the drying in a short time. There are seven pans in each set. The ore is discharged from one set to the other every 15 seconds, so that it requires $3\frac{1}{2}$ minutes for the ore to pass through the dryer. The feed is continuous, but the pans dump

* *Metallurgical and Chemical Engineering*, February 1911, vol. ix. pp. 91–95.

when a charge of about 75 lbs. has been received, giving the dryer a capacity of about 9 tons per hour, the fuel consumption being about 7 lbs. to 8 lbs. coal per ton ore dried. From the dryer the ore passes to screen and rolls, and thence to roasting furnaces of a circular, multiple-hearth type. Each furnace has six hearths 14 feet in diameter. The capacity is 24 tons per twenty-four hours. The temperature of the three lower hearths is kept at about 1100° F.

The roasted ore is cooled in a revolving drum 39 feet by 3 feet, set at a pitch of 1 inch to the foot, and cooled by water.

The magnetic separators designed by O. H. Fairchild contain three sets of electromagnets, the second and third being of higher intensity than the one immediately preceding it. The voltage is 110, and the amperage 1·5, 3, and 6 for the first, second, and third magnets respectively. Each set is composed of ten electromagnets of alternately reversed polarity, this being the principal feature of the machine. The zinc-lead-silica mixture obtained is treated by wet dressing on tables of the Wilfley and Card type.

The following analyses of concentrates represent average work :—

> Magnetic iron—Silica, 6·5 ; iron, 46·0 ; zinc, 3·0 ; lead, 2·2 per cent.
> Zinc concentrate—Silica, 7·0 ; zinc, 42·0 ; iron, 11·0 ; lead, 6·0 per cent.
> Lead concentrate—Lead, 67·0 ; zinc, 6·0 per cent.

The tailing carries about 9 per cent. zinc, 1–2 per cent. lead, and amounts to 15 to 18 per cent. of ore treated.

Occurrence and Concentration of Tin Ores.—Some notes on the occurrence and concentration of tin ores are given by C. F. Thomas,[*] who first deals with cassiterite and the commercially important associated minerals. With regard to mispickel, an extraction exceeding 1 per cent. of arsenious anhydride from tin ores is not uncommon ; after roasting selected mispickel, the residues often contain 5 per cent. cassiterite.

The extraction of mispickel is low by wet concentration, and selection previous to milling is advisable. Wet concentration of chalcopyrite and other copper-bearing minerals is also unsatisfactory. In the Calstock Mines, Cornwall, the ore averaged 0·5 to 0·7 per cent. of copper ; the concentrate previous to roasting averaged 2·5 to 3 per cent. copper.

The details of a modern plant erected in Cornwall are given, including mill, concentrators, tube-mills. calciners, and magnetic separators, &c. The future prospects of tin mining in the Transvaal, the origin of the cassiterite, &c., are also considered.

Progress in Ore Dressing.—The progress made in ore dressing in the United States and Mexico during 1910 is reviewed by H. A. Guess,[†] the record of which, in the author's opinion, compares favourably with that of any recent year. In water concentration processes, nothing note-

worthy in new machinery or arrangement has developed in the crushing of the ore. For fine crushing, the tendency has been to carry the work as far as possible with rolls. The classification of table and vanner sieves has received much attention during the year, especially in regard to the more complete removal of all slime from the feed for the tables. In cyaniding, the practice of all-sliming treatment is on the increase, and the tube-mill remains the approved machine for such work. Some recent tests in tube-milling efficiency led to the conclusion that the cyaniding efficiency increases with the percentage of solids in the feed up to 55 or 60 per cent., that it also increases with the quantity of ore fed per minute to a point which varies with the dimensions of the mill, and that the horse-power efficiency appeared to be lower in the mills of larger diameter—5 feet by 20 feet—than in the smaller mills—4 feet by 18 feet. Much attention has been devoted during the year to the development and perfecting of filtering processes, and the use of slime thickeners of the Dorr type is doing much to lessen the work of the filters. The best known filters are the Butters, Merrill, Burt, Grothe-Carter, Ridgeway, Kelly, Moore, and Blaisdell.

Rough Ore Crushing.—A description is given of an unique ore crusher known as the Symons disc crusher.* It consists of two saucer-shaped discs of manganese steel, set at a slight angle to each other, and revolved rapidly in the same direction, each running true on its own axis. Neither disc vibrates or moves sideways. The ore is fed in between the discs through a central opening in one of them and drops until caught between the discs and so crushed.

A 48-inch disc crusher takes 7-inch pieces, and will crush to any size between 3 inches and $\frac{3}{8}$ inch. Its capacity when producing 1-inch pieces is from 50 to 90 tons per hour. The 24-inch disc crusher takes $3\frac{1}{2}$ to 4 inch pieces, and reduces to any size down to $\frac{1}{4}$ inch.

Its capacity on $\frac{1}{4}$-inch product is about 7 tons per hour. The crushers can be readily adjusted to any sized product required.

Separation of Solids and Liquids.—A new machine for the separation of liquids and solids by centrifugal force is described.† This machine has been designed for the De Laval Separator Company, and consists of a cylinder 30 inches in diameter by 8 feet long, revolving at a normal speed of 320 revolutions per minute, equal to a peripheral speed of 2513 lineal feet per minute. Thus a product delivered into the machine is subjected to a centrifugal pressure which causes the heavier part (solid) to settle to the periphery. The material is fed through a hollow arm of the supporting spider to a revolving cone and into the cylinder. The material thus attains the peripheral speed of the machine and the coarser particles are at once separated, and by a series of broken helical scrapers, operating at a different speed, are drawn up an incline or cone, freed from liquid, and discharged into the receiving chamber.

* *Mines and Methods*, February 1911, vol. ii. p. 138.
† *Metallurgical and Chemical Engineering*, March 1911, vol. ix. pp. 147-148.

The liquid is discharged at the opposite end. Mixtures containing from 2 or 3 to 15 or 20 per cent. of solids in water can be treated by this machine.

Tin Sluicing in Tasmania.—An abstract is given of a paper by E. Edwards * on tin sluicing in Tasmania, published in the Bulletin of the Australasian Institute of Mining Engineers, April 1910. The nature of the deposits is described, and the essentials for successful hydraulic mining are given.

The results obtained by bore holes and shafts for sampling and assaying are given, and the various methods of conducting the concentration process are discussed.

In the particular case under notice the concentration is carried out in four stages. Suppose the ground averages 5 lbs. per cubic yard, this is less than 0·1 per cent. First concentration in the head sluice should be to 1–3 per cent. Second concentration in the sluice should give 60 to 70 per cent. down to 30 per cent. at tail. Third concentration, the preliminary streaming, over 70 per cent. Fourth concentration, the final streamed tin, 75 per cent.

Zinc Ore Dressing at the Wellington Mine, Colorado.— The methods adopted in the dressing of zinc ores at the Wellington Mine, Colorado, are described by H. C. Parmelee. † The crude ores contain about 17 per cent. zinc, 8 per cent. lead, 20 per cent. iron, and 20 per cent. silica. At present the mill uses a system of wet dressing only, but preparations are being made to instal roasters and magnetic separators to treat a low grade zinc-iron middling which is now accumulating. The plant for the crushing, screening, and jigging of the ores is described, and diagrams of the jigs are included.

The classification of the undersize in a Henderson classifier is described, as is also the concentration of the products on Wilfley and Card tables. The zinc concentrate as shipped assays between 35 and 40 per cent. zinc, with about 2 per cent. lead ; the lead concentrate assays 45 per cent. lead and 5 per cent. zinc. The zinc-iron middlings are of two grades, a high grade middling shipped to pigment works, and a low grade middling now being saved for roasting and magnetic treatment.

* *Mines and Minerals*, December 1910, vol. xxxi. pp. 309–314.
† *Metallurgical and Chemical Engineering*, November 1910, vol. viii. pp. 620-622.

EXTRACTION OF METALS.

CONTENTS.

I.—*COPPER.*

An Improvement in Hot-Blast Smelting.—A blast - furnace embodying several novel features is described by C. H. Mace.[*] This type of furnace is the invention of A. R. Partridge, and is notable for the absence of tuyeres, and for the fact that the blast is pre-heated by molten slag. In place of a bustle pipe and tuyeres are a crucible chamber and a complete open space of $360°$ circumference and $2\frac{1}{2}$ inches in height between the top of the crucible and the bottom of the bosh where the water jacket terminates. The slag is not tapped, but overflows into small shallow cars which travel slowly under the slag taps and thence around the circumference of the slag box, finally dumping automatically into a boot in a water seal below.

The blast enters the slag box above the point where the cars discharge, passes over the cars of molten slag and up into the crucible chamber, thus entering the smelting zone at a high temperature.

This furnace, according to the author, has demonstrated the fact that the introduction of the blast through tuyeres at a high pressure is erroneous, both for a reducing and an oxidising smelt. An excessive blast-forge causes heavy flue dust, an increase in the height of the fusion zone, and losses of metals by volatilisation ; all these disadvantages are overcome in this furnace, and a pressure of 4 ounces in small furnaces to 12 ounces in large furnaces is maintained. In other words, the actual air inlet is increased, and an enormous volume of air enters the furnace at a low pressure and velocity.

The operations of blowing in and blowing out the furnace are very simple and rapid.

It is believed that this smelter will prove of great value to base metal mining in general, and to small inaccessible copper and lead properties in particular.

[*] *Metallurgical and Chemical Engineering,* December 1910, vol. viii. pp. 671–673.

Blast Roasting.—Blast roasting, which is a generic term for the process of forcing air through finely-divided metallic sulphide with the object of roasting and agglomerating in a single operation, is described by H. O. Hofman. *   At first the process was confined to a galena concentrate ; lime, limestone, or gypsum was added, to serve both as a diluent to keep separate the particles of galena that they might be thoroughly oxidised, and as a flux that the partly roasted ore might be agglomerated by the formation of some slag. Later it was extended to treat other metallic sulphides. There are two methods of applying the process, the up-draught and the down-draught systems. The former is employed at the Huntington-Heberlin plant of the Consolidated Mining and Smelting Company of Canada, at Trail, British Columbia, and at the Murray plant of the American Smelting and Refining Company, Utah ; and the practice at these works is described, together with that at other works where the up-draught system has been adopted. Blast-roasting with up-draught pots is accompanied by several disadvantages. The leading ones are :— (1) the ore is exposed for a long time to the influence of hot gases, and this with lead ore means loss of metal ; (2) the process is intermittent ; (3) the pot requires more or less constant attention in filling, blowing, and discharging ; (4) the amount of fines that has to be re-treated is liable to be large ; (5) the handling of fines causes much loss by dusting ; (6) the cake is unevenly sintered ; (7) the breaking of the cake is expensive, even when done mechanically, and it is unhealthy if done by hand. These disadvantages appear to have been overcome by the Dwight-Lloyd sintering process and apparatus, in which the ore is exposed only for a short time to the influence of heat and blast : that is, approximately 1 minute for each 1 per cent. of sulphur ; the process is continuous, and when once adjusted requires little or no attention ; it makes very little fines, and furnishes a porous sinter of coke-like structure, which usually is small enough to go direct to the blast-furnace. This is a down-draught process, and is in use at the works of the Cerro de Pasco Mining Company in Peru.

Changes during Leaching Processes.—In a paper on the " Secondary enrichment in the copper deposits of Huelva, Spain," A. M. Finlayson,† after dealing with the subject from a geological point of view, gives particulars of the microscopic examination of specimens from leach heaps to observe the changes which take place during the process. Experience with the leaching methods adopted in this field has demonstrated a great difference in the rate of extraction of the copper according to the form in which it is present in the ore ; chalcocite being much more amenable to the process than chalcopyrite, it would seem also possible that a slight film of chalcocite round the grains of chalcopyrite would enable the extraction of the copper to proceed under the influence of air and moisture without great hindrance.

* *Bulletin of the American Institute of Mining Engineers*, 1910, pp. 473.
† *Bulletin of the Institution of Mining and Metallurgy*, November 1910, No. 74, p. 10.

The copper content of the specimens examined prior to leaching varied 0·9 to 1·8 per cent., and the results of the observations are as follows :—

(1) The specimens of ore prior to leaching show fine grains and strings of chalcopyrite, and in five out of fifteen specimens taken, thin envelopes of chalcocite were visible around or adjoining some of the chalcopyrite grains.

(2) Ore taken from heaps which are undergoing oxidation shows a highly porous pyrites matrix traversed by innumerable cracks. The chalcopyrite grains become surrounded by envelopes of greyish-black chalcocite, which also appears as threads penetrating and replacing the chalcopyrite. The chalcocite gradually works its way to the centre of the grains, and also alters round its outer edges to covellite and to oxides of copper. The process thus consists of a gradual concentration of copper towards the centre of the grains, accompanied by oxidation on their exterior.

(3) The next stage is illustrated in ore taken from heaps which are undergoing leaching. The chalcocite is here being gradually corroded and dissolved by the acid solutions and removed from the exterior of the grains as copper sulphate. As the chalcocite is removed much faster than it is formed, the leaching becomes slower when only chalcopyrite is left, and the stage is at length reached when a second period of oxidation is necessary. The chalcocite is clearly, in the inner ores, an intermediate product, formed during the oxidation, and rapidly removed during the subsequent leaching. The leached ore shows corroded nuclei of chalcopyrite, from which practically all the chalcocite has been dissolved out.

(4) Finally, specimens were examined from leached heaps which assayed only 0·3 per cent. of copper. The extremely porous nature of the ore, and the great corrosion which it had undergone, made it difficult to get a satisfactorily smooth surface. Small residual grains of corroded chalcopyrite were, however, observed.

The leaching process is thus essentially the same in principle as that which goes on in nature in the secondary enrichment of the lodes. There is a continual kernel-concentration of copper, effected by the formation of secondary chalcocite, which is finally attacked by acid solutions and transported. The gossan through which the solutions reach the sulphides is represented by the thin transitory oxidised films encircling the chalcocite, and formed during the oxidation of the heaps. The ore of the leached heaps corresponds to the ore of the zone of sulphide-impoverishment immediately beneath the gossan of the lodes.

Charcoal in the Copper Blast-Furnace.—A note has been contributed * on the use of charcoal in the blast-furnace for smelting copper ore. In using charcoal instead of coke, it was found necessary to reduce the blast pressure slightly on account of the shower of sparks that was thrown upon the feed-floor every time the charge doors were opened. A considerable amount of charcoal is ground to dust by the movement of the charge in the furnace, and these fines are blown out of the furnace.

* *Engineering and Mining Journal,* vol. xci. p. 110.

To compensate for this loss it is found necessary to use a greater weight of charcoal per ton of charge than coke, and, generally speaking, where wood is plentiful and coke expensive, wood-fired reverberatory furnaces will be more suitable for smelting copper ore than a blast-furnace using charcoal.

Converter Flame Indications during the Bessemerising of Copper Matte.—The successive stages in the bessemerising of copper mattes, as indicated by the converter flame, are described by D. M. Levy,[*] who has made use of Lumière colour photographs to illustrate and furnish a permanent record of the colour effects produced. There are two main stages in the process, the first being the elimination of the iron sulphide, and the second the final sulphur elimination. The first stage is known as the slagging stage, and is characterised by a green flame, caused chiefly by the formation of iron-silicate slag.

The flame during the second period—that is, the final elimination of the sulphur and reduction of copper—is smaller, thin, fairly non-luminous, and red-purple to bronze-purple in colour. In addition to these main colour stages, there is a rich red-brown colour on first blowing and a blue-white colour at the end of the slagging stage. The first of these is partly due to coal thrown in, and also to foreign ingredients in the matte, which are first oxidised. The blue-white flame indicates that most of the iron has been slagged off, that the white-metal stage has been reached, and that copper silicate is being formed, to which latter fact the colour of the flame is to be attributed. The copper oxide formed appears to form the silicate in presence of much slag rather than attack the copper sulphide. The marked green and blue colour effects are not produced unless the oxides of iron and copper are being slagged.

When the white-metal stage is reached the slag is poured off and the second stage of the blow commences with a vivid red-brown flame and smoke; this gradually decreases and a thin red-purple flame of some brightness with thin smoke results, and continues with very slight change to the end of the blow. The temperature of the operation can be judged by the flame, a red-brown indicating the correct temperature; if too red, the metal is too cold, and coal is thrown in; if too orange, the metal is too hot and a "dope" charge of scrap, cleanings, and siliceous material is added. The end of the blow is most difficult to judge, the size and colour of the flame being some criterion, but a very important guide is the emission of little shots of copper which no longer stick to the hood over the converter, but rebound from it.

In general character the colour sequence of the converter flames does not vary much in different localities, but the body and luminosity depend very largely on the nature of the charge and working conditions.

The colours are intensified by very hot metal, high-blast pressure, and rapid working, and also to a great extent by the presence of secondary constituents in the matte such as zinc, lead, or arsenic, which liberate heavy white fumes and increase the luminosity considerably.

[*] *Bulletin of the Institution of Mining and Metallurgy*, November 1910, No. 74.

Copper and Copper-Nickel Mattes in the Bessemer Converter. —D. H. Browne * points out that nickel was formerly regarded as an element replacing iron in copper mattes, and it was believed that the same laws which governed the elimination of iron could be applied to nickel. This conception has lately undergone a complete change, and nickel in all its stages is now regarded as an element replacing copper ; in other words, copper-nickel is considered now as two elements, but as one metal.

In investigations on Monel metal a great many experiments were made on the conversion of mattes, both high copper and high nickel, the composition of the mattes and the changes produced by the blow being studied. In all cases certain agreements were found leading to the following conclusions :—

1. Nickel is not an element replacing iron in matte.
2. Nickel-copper alloys act in the matte-blow like one metal.
3. Nickel-copper alloys follow, during the matte-blow, exactly the same laws as govern the behaviour of copper alone.

This leads to the question : What are the laws governing the production of metallic copper, and what are the relations of copper to sulphur and iron during the Bessemer blow ?

Copper-nickel alloys form, as far as conversion is concerned, one homogeneous metal. They act together—no matter what the proportion may be ; high copper and low nickel, or *vice versâ*, they present in conversion the same curious resistance to oxidation, and their relations towards iron are absolutely similar to the relations of copper alone.

The best known of these alloys is Monel metal, the matte of which is blown till the iron is eliminated, the sulphur removed by roasting, and the combined oxides reduced to metal. As the compound metals have never been separated from each other, the particles of each seem to be in more intimate contact than can be attained by any synthetic method of manufacture. The author was not able to produce, by melting copper and nickel together, an alloy having the same physical properties as the alloy produced direct from the matte.

There seems to be some physical reason why nickel and copper cling together in this way, and this resistance to oxidation in the converter is in some way connected with the resistance of the finished alloy to oxidation and corrosion, but what this reason is, is not at present known. A comparison of the properties of copper, nickel, and Monel metal are given below :—

	Copper, Rolled.	Nickel, Rolled.	Monel Metal.		
			Cast.	Rolled.	Annealed.
Tensile strength, lbs. per sq. in.	34,000	75,500	85,000	100,000	110,000
Elastic limit, lbs. per sq. in. .	18,000	21,000	40,000	50,000	80,000
Elongation in 2 in., per cent. .	52	43·9	25	30	25
Contraction, per cent. . .	57	57	25	50	50
Melting-point, °C. . . .	1,084	1,500	1,360	...	...

* *Bulletin of the American Institute of Mining Engineers*, 1910, p. 285.

Copper Blast-furnace Tops.—An account is given by N. H. Emmons * of the development of blast-furnace construction, which has become necessary in adapting the furnace to be a "burner" for the manufacture of sulphuric acid.

Before the Tennessee Copper Company decided to construct an acid plant, the standard type of brick-top furnace, supported by structural steel, was used, and gave satisfactory tests for temperature and strength of gas, but on using the acid plant the flue had to be fitted with a damper to force the gas into the plant, and trouble arose.

The furnace top would not withstand the higher temperature, and the structural steel of the furnace warped and twisted badly.

In consequence of this, a new top was designed, which was low, with brick-lined flues at each end, below the feed-floor leading to the main dust-chamber. The trouble with this furnace was that the top was too low, and when the doors were opened for charging or barring, smoke and flame shot out, making the work difficult and unpleasant. A further experiment was made with a higher top, enlarged flue connections, and water-jackets extending above feed-floor ; air at 45 ounces pressure was blown through the jackets. The latest form of furnace tops consists entirely of cast iron from the feed-floor to the first brick arch, and is called the tubular-top furnace ; the flues are lined with tongue and groove brick clear through to the dust-chamber.

Details are given as to temperature of gases, charges, and dimensions of furnaces.

Copper in Peru.—The conditions of copper mining in Peru are described by F. E. Ross, † the most notable recent mining development being the undertaking of the Ferrobamba Company, Ltd., for the opening up of large bodies of high grade copper ores in Southern Peru ; while, during 1910, the Serra di Pasco Mining Company twice made new records in the production of copper bullion, 4,926,217 lbs. having been produced in October, and 5,175,000 lbs. in December.

Copper Precipitation in the Butte District.—There are precipitated in the Butte district ‡ about 700,000 lbs. of copper per month from mine and tailing waters. Of this quantity about 550,000 lbs. are recovered from copper-bearing mine water, and 150,000 lbs. from water percolating old tailing dumps. The original tailing carried about 1 per cent. copper, and was deposited on a bed of slime, which provides a very effective impervious stratum, preventing the loss of leaching water.

The dump is divided into two sections, and has a total area of about 10 acres. The surface of each section is arranged in terraced ponds, into which the leaching water is pumped by means of Morris phosphor-bronze centrifugal pumps.

* *Bulletin of the American Institute of Mining Engineers*, February 1911, No. 50, pp. 119-134.
† *Engineering and Mining Journal*, 1910, vol. xci. p. 463.
‡ *Metallurgical and Chemical Engineering*, November 1910, vol. viii. pp. 614-616.

The leaching water used is mine water, which has been treated previously in a precipitation plant, when 95 per cent. of its copper content has been recovered, leaving 0·003 to 0·004 per cent. copper. The percolating water is collected in tunnels extending through the bottom of the dump, and is finally discharged into a sump, whence it is pumped to the precipitating launders. A section of the dump surface is allowed to dry out periodically, so that the accumulation of precipitated iron compounds may be removed, and the dump material allowed to oxidise before further leaching. The accumulation of iron compounds prevents leaching, and is occasionally scraped from the surface. By this treatment the dump yields a constant supply of copper, this particular dump having been leached continuously for four years, with no apparent diminution in yield. The leaching waters carry from 0·015 to 0·03 per cent. copper, and the launder system of precipitation is preferred to the old-style tower system. The launders are 4 feet wide, 1 foot deep, and have a fall of $\frac{1}{2}$ inch to the foot. Scrap iron and tin cans are used for precipitation. Iron is consumed at the rate of $1\frac{1}{2}$ lbs. for each pound of copper precipitated. The precipitated copper is swept from the iron every two hours during the day, and is carried to a sump by means of a stream of water.

From the sump the copper is shovelled on to a drying platform, and is shipped to the refinery with about 15 per cent. moisture.

The recovered precipitate assays about 75 per cent. copper and 8 per cent. iron.

About 90 per cent. of the copper in solution is precipitated. Payment for the precipitate is made on the wet assay, less 1·3 per cent., and at 4 cents less than the market price of copper.

Copper Smelting in British Columbia.—Recent developments at the Granby smelter are described by F. E. Lathe.* The smelter was built between 1899 and 1900 to treat the low grade copper-gold-silver ore produced from the mines at Phœnix. The ore is nearly self-fluxing, and the blister copper contains about 99 per cent. of copper, while the converter slag, rich in iron, and containing some copper, gold, and silver, is returned to the blast-furnace, being available both as a flux and for its metallic contents. In 1906 the extensions made had raised the capacity of the smelter to 3000 tons per day. There are now eight blast-furnaces charging coke and ore. The blast varies from 24 to 28 ounces, and each furnace takes about 25,000 cubic feet of air per minute. The ores are low in copper and sulphur, but a high ratio of concentration is possible, and a recovery of 85 per cent. is regularly attained. The copper content of the ore varies from 1·2 to 1·6 per cent., the silica amounting to 35 per cent., and the iron to 13 per cent. The copper-bearing mineral is chalcopyrite, which carries gold and silver. The converter equipment consists of ten converter shells, 84 by 126 inches; three shells, 72 by 100 inches; and three stands for the large and one stand for the small converters. The yearly capacity of the plant is

* *Journal of Canadian Mining Institute*, 1910, vol. xiii. p. 273.

fully 40,000,000 lbs. of copper. The enlargement of the furnaces has shown that the tonnage smelted per square foot of tuyere is greater for longer than for short furnaces. The deeper the column of ore in a furnace, the less sulphur will be burnt off, and the result is a lower grade of matte, which, requiring more iron to unite with the sulphur, makes more siliceous slag. With the deepening of the Granby furnaces, the copper in the matte was decreased by 5 to 10 per cent., but this was the only disadvantage encountered, as the smaller the amount of sulphur burned off in a furnace, the less chance there is of the formation of metallics.

Electrical Smelting of Copper in Norway.—Trial smeltings of copper,* with an electric furnace of 1000 horse-power, and an estimated producing capacity of 2000 tons per annum, have been commenced at the Ilen Smelting Works, Trondhjem. A consignment of 25 metric tons of pure copper, the first copper produced by electrical smelting in Norway, has recently been exported from the Bitavaira Mines at Kaafjord, near Lyngör. At Christiansand the electrical smelting and refining of nickel and copper is about to be undertaken by the " A/s Kristianssands Nikkelraffineringsverk."

Electrolytic Separation of Copper.—J. B. C. Kershaw † traces the development of the electrolytic process of copper refining from the original inception of the process by James Elkington about the year 1869, when he planned and started the first electrolytic copper refinery at Pembrey, in South Wales. The installation is said to have consisted of one hundred earthenware cells, 33 inches high, by 17 inches diameter; the total annual output of the works being limited to 250 tons. Comparison is made with the Raritan Copper Works at Perth Amboy, N.J., U.S.A., whose output is said to be 63,000 tons of refined copper per annum; the world's total annual output of electrolytic copper being 400,000 tons. Three illustrations are given of the tank houses, respectively at the Elmore Works, Leeds; Boltons', Widnes; and the Raritan Refinery, Perth Amboy. A further illustration shows the Walker and Thums anode casting machine. The value of gold and silver recovered per annum from slimes in American refineries is £4,000,000.

Leaching applied to Copper Ore.—In a series of articles W. L. Austin ‡ gives a review of results accomplished in the leaching of copper ores, with suggestions as to methods best adapted to further progress. It is pointed out that the extraction of copper from an ore by solution followed by precipitation in metallic form has much to commend it, although up to the present it has not met with any marked degree of commercial success. Particular attention is paid to the cost of the

solution and the cost of regenerating the spent liquors. Copper is easily brought into solution by ferric salts, which are cheaply obtainable in almost any locality. Experiments carried out at Cananea in 1907 are described, in which mill-tailings and flue-dust from the furnaces were treated by percolation with ferric sulphate solution and the copper precipitated by means of metallic iron, the spent solutions being regenerated by blowing heated air through them. The chemical reactions taking place during this process are fully described, and it is shown that the pyrites in the ore reduces the ferric salts, causing a waste of the solvent ; zinc minerals are also readily attacked, and the zinc so extracted gradually accumulates in the solution. At Cananea, the oxidation of the ferrous to the ferric sulphate was found to be a serious problem, as the transformation was very slow, and it was concluded that on a satisfactory solution to this problem the success of the process depends. Estimated costs of experiments are given. One test on flue-dust assaying 7·5 per cent. of copper showed an extraction of 94 to 96 per cent. The experiments at Cananea did not, however, lead to the adoption of the process. Leaching experiments at the Ray Mine, carried out in 1905, are next described ; the ore averaged about 2·2 per cent. copper.

Leaching with sulphuric acid was found to remove a small percentage of copper from the ore, but did not attack that portion present as sulphide, but a hot acid solution of ferric sulphate was found to extract practically the whole of the copper.

In the experiments the ferric sulphate was allowed to percolate through the coarse material, the copper being precipitated by the electric current, an effort being at the same time made to regenerate the solution. Two methods of preparing the ferric salt were investigated—the first by chemical means by precipitating the copper on iron, neutralising the ferrous liquor by milk of lime, and then oxidising the ferrous liquor by compressed air, the ferric hydrate thus produced being dissolved in sulphuric acid. This method proved to be too expensive. The second method was by electrolysis, and this appears to have given more satisfactory results, although the tests were not carried far enough to establish its economic value. The work at the Ray Mines on leaching methods was discontinued, although several features of the process present attractive possibilities.

Estimated costs of treating ore by this method, and also by a wet concentration method, are given. The Siemens' process for producing copper direct from ores is next described ; the process, introduced in 1890, consists of dissolving the copper out of the raw ore by means of ferric sulphate, and in the subsequent removal of the metal by electrolysis, employing insoluble anodes, and regenerating the solvent liquor in the same operation. The main requisite for successful operation of this process is cheap power. It was found that some ores required a light calcination before treatment. The finely divided ore was agitated with hot ferric sulphate solution, and the pulp and solution then filter-pressed.

In laying out the plant it was sought to avoid the elevation of the corrosive ferric sulphate solution, and any apparatus that came into contact with such liquors was constructed of lead or wood.

The practical application of this process upon a working scale has been disappointing, and a similar method of treatment was attempted, in which the copper was brought into solution as chloride, but practical difficulties developed which were hard to overcome. It is evident that there is no difficulty in getting copper into solution, an extraction of 90 per cent. or more being easily obtained with ferric sulphate or chloride, the principal objection to the process being the difficulty of bringing back the solvent into an active condition. Ferric chloride has the property of dissolving the oxide of copper and of decomposing sulphides. If pyrites, pyrhotite, chalcopyrite sulphides of antimony and arsenic, galena, sphalerite, and some other minerals are boiled with ferric chloride, these are decomposed, and copper, antimony, arsenic, lead, zinc, &c., go into solution. The addition of sulphuric or hydrochloric acid assists these reactions ; in the presence of silver this metal is slowly dissolved, but apparently again precipitated. The metals lead, copper, bismuth, and antimony are all soluble in ferric chloride, and for this reason ferric chloride has been used to clean quicksilver, the mercury itself probably being attacked to some extent. A process described by O. Froelich in 1908 seems to have much to recommend its further investigation. Briefly stated, this process consists in dissolving the copper out of an ore by means of agitation with a hot ferric chloride solution, and its subsequent precipitation with metallic iron. In the regeneration of his solution, Froelich relies upon a mechanical treatment of the liquors after the copper has been removed ; for this purpose he uses an agitator. The Doetsch process is also briefly described ; this consists in leaching the copper ore in heaps with ferric chloride solution, and regenerating the resultant liquors after precipitating the copper on iron, by means of chlorine. Two years are required to extract 82 per cent. of the 2·7 per cent. copper in the ore.

A process is considered, which has been tried on the experimental scale, in which the novel features are (1) causing the lixiviant to rise through the ore, and removing in an apparatus (the leaching vat) any slime carried over ; (2) causing the lixiviant to circulate rapidly through the material treated without employing moving parts within the leaching vat ; (3) regeneration of the lixiviant by treating it with chlorine gas ; and (4) cementation with the aid of a coke-iron couple. It is shown that when coke is mixed with iron in the precipitating boxes the reaction is much more effective.

Some account is given of the use of ferrous chloride as a solvent for copper and copper oxides, and the various modifications of the Hunt and Douglas process are described.

Metallurgy of Copper during 1910.—L. S. Austin * gives a review of the metallurgy of copper during the year 1910. The conveyance of ores on belts and charge cars for feeding blast-furnaces is dealt with. The roasting of copper ores is said to be largely carried out in one or another type of McDougall roaster, which has been improved in

mechanical detail; the drop-holes of the furnaces, by which the ore falls from floor to floor, are set opposite the side-doors, and here the ore sticks to the brickwork, and is hard to remove; this brick surface has been replaced by iron plates, and from these the accumulations can easily be barred off. Reverberatory roasting is found to produce more sulphuric anhydride than blast-roasting. In reverberatory smelting it is necessary that the gases escaping should at least be at the melting-point of the slag; and the question as to the use of the waste heat of these gases becomes important. An advantage possessed by the reverberatory furnace over the blast-furnace is that the charge can be greatly varied in composition without affecting the good work. The work may be slower, but so long as the slag flows it will be clean, whereas in the blast-furnace a viscid slag eventually refuses to issue from the tap-hole and the furnace "freezes up." Another advantage of reverberatory furnace practice is that flue-dust is only made at the time of dropping the charge, and very little then. Concentrates too fine for blast-furnace treatment are generally smelted in reverberatories, and to obtain a large output the length of the furnaces has been increased to 100 feet. To retain the heat, the walls of the furnace have been increased to 30 inches, and the roof to 15 or 18 inches in thickness. So heavy a roof, however, limits the width to about 20 feet. The practice to-day seems to be to drop the charge near the firebridge end and to depend for its spreading out on its tendency to flow whilst hot and fine.

In blast-furnace design the water-jackets are now well built, the inside plate being $\frac{5}{8}$ inch, and the outside $\frac{3}{8}$ inch. There are no joints that can be attacked by the molten materials of the furnace, and jackets are made with welded joints, especially at the tuyere opening. Increase in the height of the melting column has resulted in the saving of fuel, but at the expense of the grade of the matte, since the lower column caused the elimination of more sulphur.

In copper converting the great event of the year has been the development of basic copper converting. In basic-lined converters the treatment of low-grade matte does not prevent the difficulties met with in its treatment in acid-lined converters. The question of copper-smelter smoke has received some attention, and the Cottrell process of electrostatic precipitation of the dust is making headway.

Pyritic Smelting at Leadville.—An account of early pyritic smelting carried on at the old bi-metallic smelter at Leadville is given by C. H. Doolittle * and R. P. Jarvis. The pyritic smelting of raw silver and copper-bearing ores was commenced at this smelter in 1892, and after the success of the method of smelting was established, a new plant was erected in 1893, and continued to work until 1910. Excellent supplies of suitable ores were available, heavy sulphides for producing a low-grade matte and rich siliceous ores for the concentration of this low-grade with a high-grade matte. The plant consisted of three

* *Bulletin of the American Institute of Mining Engineers*, December 1910, No. 48, pp. 1003–1016.

flat furnaces, averaging 36×160 inches at the tuyeres, and 6 feet 6 inches from tuyeres to feed-floor. The tuyeres were 13 inches above bottom of furnace. The matte and slag produced were discharged continuously into settlers, from which slag flowed continuously, and matte was tapped periodically. The gases, after passing through a flue, were treated in a scrubbing tower. The slime collected from the settling tower contained 6·0 per cent. lead, 2·5 copper, and 16 ounces of silver per ton. The smelting was carried out in two stages : the first consisted in smelting the ore to a low-grade matte ; and the second, smelting this matte with siliceous ores to a matte containing 14 to 23 per cent. copper, and about 300 ounces of silver to the ton. A charge for the first operation consisted of 2600 pounds raw ore containing 2 to 3 per cent. copper, 225 pounds limestone, 1400 pounds slag from second operation, 200 to 300 pounds flue-dust, and 325 pounds coke. About 65 per cent. of the sulphur was eliminated in the first furnace. The furnaces each treated 125 to 175 tons of raw ore in twenty-four hours ; but in the concentrating smelting 225 to 300 tons of charge were smelted in the same time. A list is given showing the supervision and labour connected with the direct operation of the plant.

The Tooele Smelter.—In a paper read before the Utah Society of Engineers, C. H. Repath * and A. G. McGregor describe the Tooele smelter. The crushing and sampling mill is first described, and then the roaster plant, which consists of two buildings, each containing sixteen McDougall calcining furnaces of the Evans-Klepetko type. From the roaster ore bins the ore is automatically fed upon a conveyer system, and passes over a Blake-Denison automatic and continuous weighing and recording machine on its way to the calciners, where it is discharged directly into the charge hoppers. The calciners have six hearths, 16 feet in diameter, and are 18 feet high. They have revolving water-cooled shafts and arms. No fuel is used other than the sulphur, the burning of which furnishes sufficient heat to do the calcining. The reverberatory plant contains five coal-fired furnaces, 19 feet in width and 102 feet in length, with a grate area of 7 feet by 16 feet. These furnaces have a maximum capacity of 300 tons of calcine in twenty-four hours. The flame, after leaving the furnace, passes through a 746 horse-power Stirling boiler, which reduces the temperature to about 600° Fahr. The slag is skimmed twice in eight hours ; it is allowed to accumulate until its depth is 3 to 4 inches above the skimming-plate.

The matte is tapped from the side of the furnace directly into the converter building.

The main converter aisle contains five electrically operated converters of the horizontal barrel type, 96 inches in diameter by 150 inches in length. The converter slag is returned to the reverberatory by means of overhead cranes. A description is also given of converter lining, the smelter power plant, and electric tramming system.

* *Metallurgical and Chemical Engineering*, January 1911, vol. ix. pp. 15–18.

Use of Petroleum in Blast-Furnaces.—E. H. Hamilton * describes the roasting and smelting of ore with oil as fuel, and gives an account of a trial made on an occasion during a scarcity of coke to keep the blast-furnace running on oil instead. The principal difficulty encountered in earlier times had been that the thick oil failed to reach the fire zone and the fire went out, so a temporary hot blast was improvised, consisting of one straight pipe around which was built a temporary brick furnace with a small oil jet beneath it. This gave a warm blast for the tuyere in which the oil was injected, and by this means the furnace was kept running for several days longer than could otherwise have been done until a supply of coke arrived. The experiment, which was inconclusive, seems, however, to suggest that oil can be used in blast-furnaces if it be heated previous to injection.

Water in Converter Air-Mains.—A. R. McKenzie † points out the danger that may arise through the condensation of water in converter air-mains, and gives two instances which have come to his notice. In one case the power-house of the smeltery was 1000 feet distant from the blast-furnace feed-floor, and the converter air-main passed through a tunnel to within 70 feet of the furnace building. Before reaching the converters the pipe was enlarged to a diameter of about 5 feet, which answered the purpose of a receiver or reservoir, and one day water was observed coming out of the tuyeres that were leaking air around the ball valves. On examining the 5-foot reservoir it was found to be full of water up to the outlets where the side connections were made to the converters, and, on tapping, no less than 100 lbs. of water were withdrawn. In designing converter plants care should be taken not to tap the converter air-main from the bottom, as in case one of the converter stalls should be shut down any length of time, the air-pipe leading from the air-main to the stall might fill with water and so cause the danger of an explosion, unless the collected water be removed. Thus at another plant where a stall which had long been idle was again put into service, and the converter connected in place and charged without examination, the water was carried to the tuyeres and blew the converter bottom to pieces.

II.—*GOLD.*

Amalgamation.—H. C. Parrish ‡ advocates inside amalgamation as being frequently advisable when there is a difficulty with the outside plates on which a scum sometimes forms in spite of precautions. The advantage of inside plate amalgamation is that the plates are always kept clean and bright by the splash of the pulp. Sufficient quicksilver must be added to the mortar to take up all the gold, but not so much as to

* *Engineering and Mining Journal*, 1911, vol. xci. p. 224.
† *Ibid.*, p. 161.
‡ *Ibid.*, p. 260.

soften the plates, and it is best added frequently and in small amounts. On the other hand, the difficulty arising from inside amalgamation is that it requires considerable experience and skill to judge if the inside plates are in condition by the appearance of the head of the outside and the feel of the inside plates.

Chemical Control of Slimes.—A system for the chemical control of slimes is suggested by H. E. Ashley.*   Recent processes of agitation and filtration have made possible the successful extraction of values from many slimes.   The tendency, when the metal is exceedingly finely disseminated, is to cut out all sand-treatment and to slime everything.   The processes employed have been almost entirely mechanical in their conception, but certain chemical considerations may greatly hinder or assist their successful operation.   Analyses fail to be of much help in the matter, and it is a common occurrence for clays of closely identical ultimate chemical constitution to show wide divergence in physical properties. It has been shown that the rate of settling of a slime, so far as temperature is concerned, varies inversely as the viscosity of the water.   It must be fully coagulated.   If an excess of the coagulant is used, the viscosity of the solution is raised and the rate of settling retarded.   To keep down viscosity, the most effective coagulant possible should be employed, so as to reduce the amount of dissolved substances in the liquid.   Particulars are given as to the effects of various solutions as coagulants.   If it be desired to settle out the granular matter, the most favourable condition is where the least amount of alkali effects full deflocculation.   This principle is capable of extensive employment in ore-washing, and wherever perfect classification is desired.   The colloid matter, being dissolved in water, does not mechanically hinder the fall of the grains.   Wherever the clayey gangue is in a suitable colloid condition, it may be dissolved away by a suitable small amount of alkali.   This fact might be of assistance in the hydraulic mining of clay-bearing gravels, and wherever clean separate grains are desired.   It is even possible that these principles, if not too expensive, can replace dredging to some extent in keeping open the channels of rivers that are clogged by fine clay.   Pure water has a decided solvent effect upon crystalline minerals.

In cases where all-sliming has proved successful a sufficient proportion of crystal mineral grains has been introduced by the fine grinding to keep the mixture of crystals and colloids open and porous for the percolation of liquids.   The more completely the colloid portion of the slimes is suppressed, the more rapidly and successfully will these processes proceed, so long as the filter-press cake will hold together.   When it is desired to leach a slime in which the proportion of colloid matter is so high as to render it difficultly pervious to water, the grains may be separated from each other by further dilution and beating to a thin slip, or the slime may be preheated.   Preheating a slime or clay is similar in nature to the cooking of glue or starch.   From 250° to 300° C. is about the upper limit of temperature required for a favourable action.

Clancy Cyanamide Process.—The Clancy cyanamide process for the treatment of refractory gold ores is fully described by J. C. Clancy [*] in a paper read before the New York section of the American Electrochemical Society. A short history is first given of the author's experiments on the treatment of refractory ores, during which it was discovered that alkaline hypochlorites, hypobromites, and hypoiodites dissolved tellurium readily and also attacked the tellurium in gold telluride crystals. These experiments were not continued owing to cost of chemicals and to the necessity of thorough washing as a preliminary to cyanide treatment. The next process was connected with the use of soluble persulphates as a preliminary treatment to cyanidation. The high cost of persulphate and the necessity for two solutions made this process expensive, and although a mixture of cyanide and persulphate was found to work satisfactorily on gold telluride crystals, with ores it was found unsatisfactory, owing to the formation of ferrocyanide, which nullified the action of the persulphate. The next step was to find some substance which would prevent the action of the ferrocyanide on the persulphate, and potassium iodide was tried with success, gold tellurides being completely dissolved in the presence of cyanide, persulphate, and iodide.

To apply this solution to the treatment of ore and maintain the chemical equilibria necessary for producing cyanogen iodide required very skilful manipulation, and this, together with the cost of chemicals, made it expensive. The next series of experiments was carried out with a view of using ozone as an oxidising agent instead of persulphate, and although satisfactory results were obtained on a small scale, the cost of machines for treatment of large quantities of ore was found to be prohibitive. The use of an electric current was next tried as a means of producing the oxidation necessary while the solution was in contact with the ore, and the first difficulty to be met was the choice of correct anodes : lead peroxide, carbon, iron, graphite, &c., were found to be more or less inefficient, and although platinum was satisfactory, its cost was prohibitive for large-scale work. After many experiments it was discovered that an anode of oxide of iron which had been melted in an electric furnace stood up under high current densities, and did not combine with the halogen compound in the cyanide solution. The advantages of the use of an iodide as the halogen salt present are :—Iodine is easily liberated from its compounds at a very low voltage ; it does not react violently upon the cyanide solutions ; it is continuously reduced from its higher state of oxidation by sulphocyanides present in the solution, and it can be liberated from its compounds in alkaline solutions. The fact that iodine forms cyanogen iodide in a slightly alkaline solution is of extreme importance in the treatment of ores, and the method of using cyanide, sulphocyanide, and a halogen compound in conjunction with the electrolysis of the solution gave excellent results in the treatment of most of the so-called refractory ores.

Experiments were next conducted on the action of the electric current on cyanate solutions, and it was found that when allowed to get hot

during electrolysis the solution became an active solvent for gold. It was thought that this change was partly due to the formation of urea, and a solution of cyanate containing a small quantity of urea and some caustic soda, after electrolysis, was also found to be an active solvent for gold. Following this discovery, experiments were tried on cyanamide with equally successful results.

It is found that when a solution of calcium cyanamide is mixed with a solution of alkaline ferrocyanide and allowed to stand for a few hours, and even after a week's standing it becomes an active solvent for gold even without the aid of electrolysis, and, when applied to the treatment of ores amenable to straight cyaniding, gives results equal to the simple treatment with cyanide ; further, this process can be used on ores which have already been treated by the cyanide process, dumps in which there exists a large proportion of Prussian blue, which, when treated with alkali, becomes soluble ferro- and ferri-cyanides.

This opens up a cheap means of treating ores amenable to the ordinary cyanide process, and to residues from which the whole of the precious metals have not been extracted, but which would not pay for ordinary cyanide treatment owing to cost of cyanide. The following is an example of using this process upon an ore amenable to cyanide treatment :—

The ore is subjected to treatment by a solution containing 1 lb. of calcium cyanamide, 1 lb. alkaline ferrocyanide, and 1 lb. of lime in 2000 lbs. of water. The proportions used are 2 of solution to 1 of ore, and treatment continued for eight or ten hours or until extraction is complete. The following is an example of the treatment of ore which has already been treated by the cyanide process, and which has been exposed to atmospheric oxygen with the formation of ferrocyanogen compounds. In this case the solution used contains 1 lb. of cyanamide and 1 to 5 lbs. of lime (this depending on the acidity of the dumps) in 2000 lbs. of water ; this, when used in the proportion of 2 or 3 parts solution to 1 of ore gives results equivalent to straight cyanide practice. If this mixture is electrolysed, the solution of the gold is extremely rapid. Other amide compounds behave in a similar manner to cyanamide.

Experiments on cyanamide in presence of a soluble iodide proved this to be an excellent solvent of tellurium and telluride of gold. The following is an outline of the method of applying the Clancy process on a large scale : The ore is crushed in a cyanide solution containing 1 lb. cyanide, 2 lbs. alkaline sulphocyanide, 2 lbs. calcium cyanamide, $\frac{1}{4}$ lb. alkaline iodide, and 20 lbs. sodium chloride, to 2000 lbs. of water.

The ore is pulped with this solution in tube-mills, &c., 2 to 3 parts of solution to 1 of ore being used. After separation of the overzine the pulp is transferred to an agitation tank to undergo electrical treatment with agitation. In the majority of cases 50 amperes per ton, used at a voltage of 5 or 6, will be sufficient. If the tank be made of iron, this may be used as cathode. It is essential to keep the protective alkalinity at $\frac{1}{10}$ lb. alkali per ton of solution. After about eight hours' treatment with the current, the solution is brought up to about 1 lb. protective alkalinity per ton by adding caustic soda, and the contents regenerated up to $\frac{5}{10}$ to $\frac{6}{10}$ lb. of cyanide per ton. This regeneration is accomplished by two hours

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more current action. The solutions are recovered for further use in the Moore filter. The cost of chemicals per ton of solution is about 71 cents, but this can be regenerated at a cost of 6 cents per ton. The cost of current is about 10 cents per ton of ore.

Crushing Machines for Cyanide Plants.—M. R. Lamb * advocates the use of steam stamps as against gravity stamps, and an extension of the use of rolls and ball tube-mills in crushing for cyanide practice. Except for the occasional manganese-silver ore, cyaniding is an almost purely mechanical process, and a simple crushing and grinding plant would consist of breaker, ball tube-mill, classifier, and pebble tube-mill, in which attendance and skill requirements would be reduced to a minimum. If rolls are preferred to the ball tube-mill, their substitution does not affect the other machines. If fuel is advantageously cheap, the plant may consist of crusher, steam stamp, classifier, and tube-mills. For small plants or with unskilled labour the slow Chilian mill has advantages. In either case, there is no work for the gravity stamp which cannot be done better by either of the other coarse crushers.

Large tonnages of hard ore are crushed advantageously to $\frac{3}{16}$ inch, or coarser, with steam stamps. Steam consumption, labour, repairs, and first cost are smaller than the corresponding items for gravity stamps. Small tonnages of hard rock are crushed advantageously with rolls, which are admittedly cheaper than gravity stamps in first cost, repairs, labour, and power, if they are not expected to crush too fine, and are not complicated with screens and elevators—as they need not be for feeding tube-mills. Large ball tube-mills are available for reducing 3-inch ore to a size suitable for feeding pebble tube-mills in one operation with no screening. Scores of these mills are in use for crushing hard, glassy clinker. Finally, small steam stamps will undoubtedly be at the disposal of the metallurgist within a short period to fill the gap in sizes of a type of mechanism the merits of which have been proved in practice.

Cyanidation in 1910.—P. Argall † discusses the progress of cyanidation during 1910. In South Africa the tendency is to use heavier stamps, the advantages claimed being reduction in initial expenditure, owing to fewer stamps being necessary, reduction in size of mill building, less shafting belts and moving parts, and less labour.

Continuous agitation is also gaining ground, and the experience gained at the Esperanza Mill, Mexico, bears out the favourable views held of this process, on a large scale. So far, zinc precipitation is still preferred to electrolytic precipitation, particularly for rich solutions, and electro-cyanide methods have failed to give satisfactory results.

Cyanidation of Ores.—In a paper presented before the Scientific Society of Colorado, W. A. Hendryx ‡ deals with the mechanical

* *Bulletin of the American Institute of Mining Engineers*, 1910, p. 551.
† *Engineering and Mining Journal*, January 7, 1911, vol. xci. p. 42.
‡ *Metallurgical and Chemical Engineering*, February 1911, vol. ix. pp. 82 85.

handling of ores during cyanidation. The author prefers in wet crushing to use a weak cyanide solution $\frac{1}{10}$ of 1 per cent. of cyanide, as this is found to increase the amalgamation, except where it is prohibited owing to the presence of a large amount of cyanicides. Not only is amalgamation increased, but a considerable amount of gold is put into solution at the battery. After crushing, the coarse gold should be amalgamated on plates, and the tailings passed to a dewatering sizer. The Hendryx combination agitator and filter is illustrated and described, and in the author's opinion an ore in which the values could be extracted in two, four, six, or eight days by leaching, could by proper agitation and aeration be equally well treated in a similar number of hours. By the use of violent and rapid mechanical agitation and heat the slime present is coagulated and curdled, so that it settles rapidly. Mechanical agitation is preferable to aerial agitation, both for coagulating the slime and for shortening the time for dissolution, as the mechanical agitator with the same horse-power will circulate the ore pulp ten times as rapidly as an air agitator. Air agitation causes emulsification of the slime, thereby retarding filtration, and prohibiting the settling of the charge for decantation. The use of air also admits carbon dioxide, which is a cyanicide, and oil is likely to be introduced from the compressor.

The author prefers the use of zinc-dust as a precipitant for the gold, because the cost of operation is very low, and almost complete precipitation is possible from a solution containing only 1 lb. or less of cyanide per ton. The use of weak solutions lessens the liability of fouling, which occurs to a greater extent when strong solutions are used.

Cyaniding in Mexico.—The cyanide plant and practice at the Minas del Tajo, Rosario, Sinaloa, Mexico, is described by G. A. Tweedy [*] and R. L. Beals.

Two classes of ore are mined and treated—oxidised and unoxidised ore. Of these two classes there are several types, differentiated by the ratio of their silver- and gold-content, proportion of heavy sulphides, and amenability to treatment by cyanidation. Each type in the unoxidised ore has its counterpart in the oxidised ore.

1. *Unoxidised Ore.*—Type 1, characterised by large proportion of galena, not rich in silver, and presenting no difficulty in treatment.

Type 2, carrying a lesser proportion of galena, accompanied, however, with zinc-blende and chalcopyrite. Whenever this chalcopyrite is found the ratio of gold to silver increases. This type of ore is amenable to treatment, but causes a larger cyanide consumption.

Type 3, clean ore, carrying very little base sulphides, with a greater ratio of silver to gold, and easily cyanided. The gangue of this type contains a considerable amount of rhodochrosite and feldspar.

2. *Oxidised Ore.*—The counterparts of these types in the oxidised ore are traced by their silver-gold content ratio, and by the presence of analogous minerals derived from the oxidation of the base sulphides, &c. For instance, Type 1 shows considerable lead carbonate; Type 2, a

lesser amount of lead carbonate, accompanied by zinc carbonate and copper carbonates and oxides ; while Type 3 contains manganese oxides, particularly psilomelane or wad.

All these types are amenable to cyanide treatment, Type 2 causing the greatest cyanide consumption, while Type 3 produces the most slime, due to the greater proportion of clay formed by the decomposition of the feldspars.

Cyaniding Slimes.—A comparison of various methods for treating pulp in air-agitation plants is made by M. R. Lamb,* who advocates the series method, which gives increased capacity and easier work. Great advantages arise as the result of installing a Dorr continuous slime thickener and connections between the various agitation tanks now in use.

Cyanide Practice in Nevada.—The conditions of cyanide practice at the Goldfield Consolidated Mines Company's works at Nevada are described by A. B. Parsons.† A feature of the practice, which is carried out in Pachuca tanks, is the addition of sodium peroxide for the purpose of introducing oxygen well into the centre of the charge. This oxidises the reducing agents which have accumulated in the solution, and thus renews the activity of the cyanide.

E. G. Spilsbury ‡ draws attention to an improvement he has made in the Pachuca process. It consists of the discovery of a method of manufacturing a diaphragm of silica sponge, which, while strong enough to support heavy weights, is so evenly porous throughout that air can be passed through it with practically little resistance, and in which, nevertheless, the pores are so minute that no solid matter, however finely divided, can pass through or even into it. In practice, this diaphragm is placed in the tank as a false bottom, resting on light channel-iron bars, 4 inches above the real bottom. The plates are either 12 by 12 or 12 by 20 inches in size, and are secured to the channel-iron supports, along the lines of intersection, by 0·25-inch carriage-bolts. When the plates are all laid, oakum is driven into the joints, which are then made completely tight by pouring in liquid cement. It is found that the consumption of cyanide per ton of ore treated under this method is much less than in either the Pachuca or the mechanically aided tanks, owing chiefly to the shorter exposure of the cyanide to the oxidising effect of the air, and also to the circumstance that it is possible to treat effectively a much thicker pulp than the other methods of agitation will permit.

Another application of this silica sponge may be found in the saving of the flue-dust of smelting operations. Experiments along this line have not yet gone far enough to warrant the publication of detailed plans and results ; but it is expected that they will yield a method

* *Bulletin of the American Institute of Mining Engineers*, 1910, p. 37.
† *Engineering and Mining Journal*, 1911, vol. xci. p. 368.
‡ *Bulletin of the American Institute of Mining Engineers*, 1910, p. 353.

replacing the present "bag-house" system for collecting all the solid particles from flue gases of every description. This material, composed of nearly pure silica, having a very high fusion-point, and invulnerable to liquid acids or acid vapours, possesses in these respects indisputable advantages over the flannel bags now used.

Danger of Explosions in Amalgam Barrels.—At the December meeting of the Chemical, Metallurgical, and Mining Society of South Africa, W. R. Dowling * called the attention of the members to the fact that some danger attends the use of barrels in mill clean-up rooms for treating black sand and other rich products.

At times gas is generated during the running of the barrels, and escapes with considerable violence when the barrels are opened. It appears that gas is generated at a dangerous pressure only when acid material containing oxidised pyrites is treated. The remedy to prevent excessive pressure seems to be the use of sufficient lime to neutralise the acid. Care should be exercised in opening the barrel to allow the gas to escape gradually, and the barrels should not be more than half full.

De Wilde Precipitation Process.—In a paper read before the Institute of Mines and Metallurgy, Mexico, G. Witteveen † describes the De Wilde process of precipitating gold from cyanide solutions by acidifying the solutions with sulphuric acid and the addition of cuprous chloride.

The results of experiments are given to show the losses of cyanide caused by the acidification of the solutions. These show that the loss of cyanide, which is not regenerated by the addition of alkaline matter, increases almost at the same rate as the strength of the original solution.

Further experiments showed that the amount of cyanide which escapes largely depends on the time the acid solution is left unprotected by alkali.

In practice, where the solutions have to be thoroughly stirred to coagulate the precipitate where they have to be decanted or filtered, there is plenty of opportunity of the hydrocyanic acid to evaporate, thus causing large losses.

Lime Reaction in Cyaniding.—The large variation in the amount of lime used in different cyanide mills is considered by T. P. Holt.‡ In the gold mines of the Black Hills from 3 to 5 pounds per ton is considered good practice, whereas in some of the Mexican plants 20 to 30 pounds is commonly used. Some metallurgists consider that in the Mexican practice too much lime is used, that it impairs extraction, and increases expense of frequent treatment of filter leaves to remove deposits of calcium carbonate. The property of lime which coagulates slime may or may not be an aid to treatment, depending on the process used.

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* *Journal of the Chemical, Metallurgical, and Mining Society of South Africa,* December 1910, vol. xi. pp. 235-239.
† *Mines and Minerals,* January 1911, vol. xxxi. pp. 342-343.
‡ *Ibid.,* March 1911, p. 475.

Where sand and slime are treated separately, low lime is used, while all-sliming plants use high lime. Silver plants use the all-sliming process and excessive lime.

There is a decided difference in the solubility of gold and silver in cyanide solutions of varying alkalinity; silver is more difficult to extract than gold, and, in addition to finer grinding and stronger solutions, often requires the addition of special chemicals. Lime increases the solubility of most of the silver minerals, but on gold it has the opposite effect; and for gold ores it is best to have only sufficient lime present to prevent loss of cyanide. The effect of alkali on native silver is the same as on gold.

Lime is an effective precipitant of soluble salts which otherwise accumulate in mill solutions, and prevent the dissociation of silver minerals. Lime is soluble in ordinary cyanide solutions to the extent of about 4 pounds per ton, and when added in excess of this amount is carried in suspension as milk of lime, but dissolves whenever the solution falls below the saturation point. The most economical amount of lime to add in any given case is a matter of experiment, and when an ore carries both gold and silver the problem is complicated.

Slime Filter at El Oro, Mexico.—E. Burt * describes a horizontal tubular filter operating under pressure from gravity, which is used in connection with the hard quartz ore treated at El Oro, in Mexico. The filter plant consists of six Burt revolving pressure filters, one 275-gallon solution pump, one 20 by 10 by 5 feet solution tank, a small acid tank, and a 40 horse-power electric motor. By the time these filters were installed, the mill tonnage was from 750 to 800 tons per twenty-four hours, but has since been gradually increased to 1000 tons. Each filter consists of a cylinder 42 inches in diameter by 40 feet long; the inside of the filter being lined with twenty filter cloths, each 26 inches wide by 10 feet long, allowing 5 in the circle and 4 to the length. The filters revolve continuously, and the life of the filter-cloths is about four months.

Slime Settler.—A simple form of slime settler or de-waterer, as used in Kalgoorlie, is described by R. E. Huntley.† The points to be noted in its favour are—(*a*) cheapness; (*b*) efficiency; (*c*) simplicity of erection; and (*d*) very little attention needed.

The settler consists of a circular vat with central inflow of the pulp and peripheral overflow of clear water. The thickened slime is discharged by means of a centrifugal pump drawing from the centre of the bottom. The vat is constructed of corrugated galvanised iron, and is provided with a false bottom in the shape of an inverted cone. When milling with fresh water, a vat 20 feet in diameter, 5 feet deep, will give a clear overflow from five stamps on oxidised and eight to ten stamps on sulphide or clear quartz ores. The sludge is always thinned down with

* *Engineering and Mining Journal*, 1911, vol. xci. p. 169.
† *Mines and Minerals*, January 1911, vol. xxxi. p. 339.

cyanide solution during the process of emptying the settler. Vats of greater depth and diameter could be used, but would have to be made of steel or corrugated iron buttressed with sand, as larger corrugated iron vats tend to go out of shape when full.

Zinc Dust Feeder for Cyanide Precipitation.—C. J. Rice * suggests an improved zinc dust feeder devised to secure an even feed of zinc dust to the solutions. The great drawback to the belt system is that the zinc dust is piled on the belt on a thick layer, and does not feed continuously as theory requires, while damage may be done to the belt if water falls on the zinc dust. The new feeder described consists of a hopper containing the zinc dust and an adjustable screw feed. The zinc dust is emulsified before it is led through launders into the solution.

III.—*LEAD.*

Smelting of Lead - Antimony Ores.—The treatment of lead-antimony sulphide ores in Mexico is described by A. W. Hahn.† The ore is carefully picked into 4-inch size, 1 to 4-inch size, fines, and waste, the fines being subsequently briquetted. The sulphides are roasted in heaps.

The furnaces are 36 inches by 60 inches, and are water-jacketed of the usual type.

The average mixture contains — silica, 30·5 per cent. : iron oxide, 24·5 per cent. ; lime, 7·0 per cent. ; alumina, 4·8 per cent. ; sulphur, 3·7 per cent. ; zinc oxide, 4·6 per cent. ; lead, 8·3 per cent. ; and antimony, 3·6 per cent. The iron ore used as flux is very variable and contains from 38 to 48 per cent. oxide of iron, and sometimes carries lead and silver values ; the limestone is good, and also carries 2 ounces of silver. The metal produced contains 70 per cent. lead, 26 per cent. antimony, and 240 ounces of silver per ton ; the slag carries 1 per cent. each of lead and antimony ; besides these a quantity of matte is produced carrying 13 per cent. lead.

A mixture of charcoal and coke is used as fuel.

Metallurgy of Lead in 1910.—H. O. Hofman ‡ describes the progress of lead metallurgy in 1910. Improvements in practice were few, but theory was steadily advanced by research work in laboratories. Thus light has been shed on the composition of the lead silicates, on the decomposition temperatures of the sulphates, and on the theory of blast-roasting generally. Useful work has also been done respecting the ignition and incandescence temperatures of arsenides and on the blast-roasting of speiss. The results obtained in these directions are briefly summarised and reviewed.

* *Engineering and Mining Journal,* 1911, vol. xci. p. 361.
† *Metallurgical and Chemical Engineering,* December 1910, vol. viii. p. 686.
‡ *Engineering and Mining Journal.* 1911, vol. xci. p. 48.

IV.—*SILVER*.

Cyaniding in Mexico.—Cyanide practice on the silver ores of Mexico, and in particular on those of the Temaxaltepec district, is described by A. F. J. Bordeaux,* who points out that the most important papers on cyaniding deal with cyaniding gold-silver ores, the gold predominating in value, so that the treatment is nearly the same as for gold ores, the losses of silver being considered of little importance. Here the treatment of silver-gold ores containing very little gold, which is more general in Mexico than elsewhere, has to be considered. The general tendency of the present practice is to slime the silver ore as much as possible, and, in order to obtain a higher efficiency, with less loss of cyanide, and greater speed, the following lines are observed :—

1. Crushing by stamps with 30- or 40-mesh screens, then crushing by Huntington or Chilian mills, through 60- or 80-mesh screens.

2. Concentration upon vanners.

3. Separation of sands and slime with *spitzkasten* or cones.

4. Sliming in tube-mills to 100- or 120-mesh screens, or even to 150-mesh, then separation again by cones for either treating the sands separately or recrushing them in tube-mills for all-sliming.

5. Treatment of the sands, if isolated, in filter-tanks.

The slimes can be treated only by decantation. An "all-sliming" plant requires less outlay of capital, and less daily expense, because it does away with a second, and sometimes a third, treatment required for the sands.

As the outlay of capital for a sand-treatment plant is very large, it has been necessary to do away with the sand or treat it together with the slime. The new Pachuca system, which is described at length, treats both sand and slime together, and avoids the necessity for a separation.

Metallurgy of Silver Ores at Cobalt.—The different methods adopted in the treatment of the ores of the Cobalt district † are discussed especially as illustrated by the flow sheets of the principal mills. The native silver in the cobalt veins occurs in flat thin sheets in vein rock, in nuggets, and occasionally in slabs up to 1 inch thick. The best ore is assorted by hand and sacked inside the mine for shipment to some smelter. The remainder of the ore is hoisted in bulk, concentrated by hand cobbing or by machinery, and the concentrates shipped to the smelters. Third-class ore may carry from 25 to 100 ounces of silver, and is concentrated up to 4000 ounces per ton. In the course of concentration about 12 per cent. of the silver is lost unless the tailings are treated by the cyanide process. Cobalt ores, owing to their complexity, are not easy to smelt, and unless carefully mixed, yield matte, spiess, and accretions, which have to be re-treated. At the present time the ore is roasted to volatilise the arsenic, antimony, and sulphur, and then smelted in the lead blast-furnace. In concentrating the lower-grade ore by means

* *Bulletin of the American Institute of Mining Engineers*, 1910, pp. 51–62.
† *Mines and Minerals*, December 1910, vol. xxxi. pp. 303–307.

of water there is a loss of from 10 to 20 per cent., making it advisable to separate all higher-grade ore first. The flow sheets of thirteen separate mills are illustrated and described.

The future of Cobalt, for a number of years to come, seems firmly established by the quantity of low-grade ore and the reduction which is being made in the cost of treatment. New veins are being constantly found in the district.

Treatment of Silver Ores in Mexico.—A method of treatment for silver ores by a combination of amalgamation and cyanide treatment is described by W. M. Brodie.* The ores treated contain galena, blende, and pyrite, and seldom carry more than 4 ounces of silver per ton, mostly as native silver, argentite, and arsenical silver. The ore is divided into two classes—high-grade, which requires no concentration, and low-grade ore, which is concentrated.

The high-grade ore is crushed in stamps, and some native coarse silver accumulates in the mortar and is removed from time to time.

The fine material from the stamps is amalgamated in 4-foot pans, the charge consisting of 1000 lbs. ore, 15 to 17 lbs. mercury, 45 lbs. sodium cyanide, 4 ounces of lead acetate, and $3\frac{1}{2}$ lbs. lime, and stock solution to make a 1 : 1 pulp. The ore is first ground six hours without mercury, and after its addition for a further ten hours. The charge is then run into a settler, where it is leached and agitated mechanically and by air for twelve hours. The pulp is then washed from mercury, thickened, and treated in Pachuca tanks.

The low-grade ore is concentrated in the ratio 50 to 1, and the concentrates so obtained are classified into high and low grade. The high-grade concentrate is amalgamated in pans, grinding occupies fourteen hours before mercury is added, and amalgamation is then carried on for two to five days. Cyanide, lime, and lead acetate are added to charge as before. On the sixth day the pan is discharged into a settler, where it is agitated mechanically and by air for six days, the solution being decanted every day and the charge made up with stock solution containing 10 lbs. cyanide per ton. The tailings from this settler are thickened and then treated in Pachuca tanks.

The low-grade concentrate is leached in percolating tanks with a solution containing cyanide, lime, and lead acetate, 50 lbs. cyanide per ton being used. The solution is left in contact for twenty-four hours, then drawn off, and the charge allowed to aerate for forty-eight hours. Stock solution containing 10 lbs. cyanide per ton is then added, allowed to stand twelve hours, and then drawn off and charge aerated twelve hours. This treatment of alternate twelve-hour treatment of percolation and aeration are continued for two months or so, or until an extraction of 95 per cent. of the silver has been obtained.

* *Mexican Mining Journal*, January 1911, vol. xii. pp. 21–23.

V.—*ZINC.*

Condensation of Zinc.—The condensation of zinc to a liquid depends on the temperature of the condenser being above the melting point of zinc, and on the avoidance of sudden cooling. The quantity of zinc unavoidably condensed as dust, owing to the vapour pressure of zinc at 500°, is calculated by A. Roitzheim [*] to be 0·662 per cent. of the charge. In actual working about 3 per cent. of dust is obtained, the excess being chiefly obtained during the first part of the reduction, before the receiver is sufficiently heated. The escaping current of carbon monoxide does not retard condensation.

Direct Extraction of Zinc.—Experiments to test the possibility of obtaining liquid zinc direct from blende have been made by F. Thomas. [†] It is found that blende dissolves in a eutectic mixture of sodium, potassium, and manganese silicates to the extent of only 0·5 per cent. at 900°, and only a very small yield of zinc is obtained in a Borchers electrolytic furnace. Better yields (up to 67 per cent.) are obtained in a closed furnace under pressure, but a large part is in the form of zinc-dust. Blende dissolves more readily in a mixture of sodium and iron sulphides (Na_2S,FeS), which melts at 661°, but the yield of zinc on electrolysis is again small, mainly owing to "pulverisation" of the metal at the cathode. The addition of lead sulphide in order to prevent this pulverisation reduces the fluidity of the bath too greatly. Iron does not reduce zinc sulphide in a sulphide bath at 920° to 960°.

Grading and Distillation of Zinc Ores. — The unsatisfactory nature of the usual plans adopted in grading zinc ores brought to the distilling works is discussed in an address to the Rhenish and Belgian zinc smelters by F. Juretzka. [‡] The methods of chemical analysis of zinc ores are still very imperfect, and ores of identical percentage composition may give very different results on distillation, chiefly on account of the varying porosity of the mass during reduction. The methods of heating the muffles are also discussed. In working ores free from zinc silicate, the temperature of the muffle should not exceed 1350° to 1373°, but the muffle should be capable of resisting a temperature of 1550°. In the best working the loss of zinc still amounts to 4·5 units, 2 of which are due to imperfect condensation, and 2·5 units to zinc remaining in the residue. As damaged retorts, &c., account for another 0·5 to 1·5 units, the total loss is 5 to 6·5 units, or 10 to 14 per cent. of the zinc in the ore. It is unlikely that this figure is capable of further reduction.

Roasting Zinc Blende.—The influence of steam and hydrocarbon vapours on the roasting of zinc blende has been studied by F. Thomas, [§] the use of organic substances as briquetting material and the introduction

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* *Metallurgie*, 1910, vol. vii. p. 607. † *Ibid.*, p. 706.
‡ *Ibid.*, 1911, vol. viii. p. 1. § *Ibid.*, 1910, vol. vii. pp. 610, 637.

of steam into the furnace being known to have a favourable influence on the roasting of zinc ores. In the presence of steam, zinc sulphate is decomposed at a temperature 100° lower than in dry air. The best results are obtained by briquetting the ore with tar or pitch-powder, roasting in the oxidising flame from a gas-producer at 700° to 750°, finally raising the temperature to 820°. The process is most rapid in a mechanical roasting furnace.

VI.—*MISCELLANEOUS*.

Condensation of Fume and Neutralisation of Furnace Gases. —The various methods used for the condensation of furnace fumes are reviewed and considered by F. T. Havard.* Notwithstanding the proved efficiency of the bag-house and the general opinion since 1860 that lead fume must be filtered to insure recovery of values, costly attempts are still being made to secure this object by washing. J. B. Wynne has described an extremely thorough and economical method of washing gases, with the primary object of recovering fumes containing lead, silver, and antimony. By these methods 50 to 60 per cent. of the lead, 80 to 90 per cent. of the antimony, and 40 to 50 per cent. of the silver may be recovered. In recovering fume from copper furnaces, other methods than by the bag-house may be preferable—for example, at Great Falls a million Roesing wires, suspended in the flue chamber and cooled in places by introduced air, collect most of the values, and may be better suited to a plant smelting 4000 to 5000 tons of copper ore a day. On the other hand, in Mansfeld, where the gases are used in internal-combustion engines, it is necessary to remove the finest particles of fume, and Theisen washers are used.

The author gives a history of the condensation of fume, which illustrates the small progress and lack of originality shown between 1780 and 1880 ; in the majority of cases water-spraying was used. Since 1880 progress has consisted mainly in the development of flue-building ; the employment of duck, woollen, and asbestos-thread bags ; and the installation in more than an experimental way of the zinc oxide method of neutralising acid gases, and the Cottrell method of precipitating fume and acid. The principal modern methods for condensing fume are :—(1) Settling the dust and fume from the gases in a comparatively quiescent state in chambers. (2) Cooling the gases by admission of air, by radiation, and by spraying with cold water. (3) Recovery of fume by subjecting the gases to filtration or friction, such as by bag-filters, baffles of metal sheets or wires hung in a flue, or by passing the gases through centrifugal washers. (4) Precipitation of fume by passing the gases through a vessel charged at numerous points with static electricity.

* *Bulletin of the American Institute of Mining Engineers*, August 1910, No. 44, pp. 599–615.

The chief methods employed in the cooling of the gases are—(*a*) water spraying; (*b*) cooling the flues by circulating water about them; by presenting cool obstacles to the passage of the gases; by the introduction of cold air into the chambers; and finally, by building flues of great length and with thin walls to secure cooling by radiation. The most complete system of water-condensation known to the author is at the antimony smeltery at Brionde; here the water is sprayed directly against the blades of the fans which draw the gases from the furnace. It is probable that greater convenience and economy will be secured for the bag-house by the adoption of mechanical means for shaking and for the purpose of fume condensation, only the filtering through textile fabric may prove better than any system of filtration through water. Exceptions may be made in the case of the antimony smelter, who will use centrifugal scrubbers; the iron smelter, who will use Theisen washers; and the copper smelter, who will use friction air-cooling methods and Roesing wires or Frendeuberg plates.

It is found that arsenic deposits completely in the filter bags. To condense arsenic it is possible that some cooling process, such as freezing on the Gayley principle, may be developed.

Whenever silver is smelted a bag-house or filter of some kind has to be used to recover losses.

For zinc fume, condensation by radiation, air-cooling, and filtering through bags is effective and as economical as any other satisfactory method. Passing on to the consideration of the neutralisation of furnace gases, the various methods which have been proposed are given. In 1880 Winkler suggested passing the fume through three contiguous chambers filled with limestone and covered with a perforated wooden roof. Water was sprayed through the roof on to the limestone, the sulphurous acid was absorbed by the water, and the acid water neutralised by the lime. Then Fleitmann proposed to pass the gases through a shaft furnace filled with iron oxide and coke, with the entrance of sufficient air to burn the fuel. The oxides of sulphur were to be reduced, and the iron sulphide collected at the bottom of the furnace. This method probably never passed the experimental stage. A distinct advance was made in 1881 by Schnabel: zinc oxide is moistened and distributed through a quantity of filter material such as heather: in this case the zinc oxide combines with the sulphur dioxide, forming zinc sulphide, from which it was proposed to recover the zinc oxide by roasting. Precht suggested in 1882 the use of hydroxides of alumina and magnesia as absorbents.

A modification of Schnabel's process has been used in Utah: zinc oxide in the form of dust is used on the bags or distributed in the form of fume in the gases to neutralise and collect the sulphuric acid. It has been suggested that sulphurous acid may be condensed by a freezing system similar to the Gayley method. In 1907 Carpenter patented a process which covered the following points :—

(1) Separation of sulphur dioxide by freezing and recovery of sulphur by reduction.

(2) Passing the gases through a reducing atmosphere and recovering the reduced sulphur by settling or filtration.

(3) Converting part of the sulphur dioxide into sulphuretted hydrogen and producing sulphur by the interaction of the two gases.

(4) Converting the whole of the sulphur dioxide into sulphuretted hydrogen, and producing sulphur from this by means of the Clause-Chance kiln.

No results of experiments on a practical scale seem available.

Extraction of Metals from Speises.—Attention is called to the large quantities of valuable metal wasted in the form of speise in many smelting works in an article by C. Guillemin.* Roasting in reverberatory furnaces can only be applied to ground material, and is usually too costly. Bessemerising is very successful, the heat evolved by the oxidation being amply sufficient to keep the mass fluid, but speise attacks metals and both acid and basic linings. Graphite linings may be eventually employed. By mixing the ground speise with a less fusible material, such as limestone, slag from copper matte-smelting, or sand, most of the arsenic and antimony may be removed by a blast of air in a converter at dull redness before sintering sets in. The fuel necessary for ignition is introduced into the converter at starting. Speise rich in arsenic yields a good product with only a small quantity of added material, the difference in behaviour of speises rich and poor in arsenic appearing to depend on the porosity of the resulting mass. Thus a speise containing 40 per cent. of arsenic, 4·5 per cent. lead, 2·25 per cent. copper, 0·7 per cent. nickel and cobalt, 0·3 per cent. antimony, and 0·275 per cent. silver, gave the best results, with only a small addition of limestone in the converter.

Manufacture of Aluminium.—Some details are given by W. Clacher † of the manufacture of aluminium, as carried out by the British Aluminium Company, Limited. The metal is reduced at the point of contact of the carbon anodes of the molten electrolyte, which consists of alumina and cryolite.

The carbon oxidises and burns away, and the metal sinks to the bottom of the carbon-lined furnace. The metal generally contains over 99·5 per cent. aluminium, this purity being due to the fact that pure materials only are used, the carbon being 99 per cent. and the alumina 99·9. In the furnace, 10-inch carbon blocks are arranged in sets of twelve. The current is obtained from 50-volt dynamos. The bottom of the furnace consists of a cast-iron plate somewhat of the form of a grid, the interspaces being rammed with carbon and the whole plate covered. This form of bottom makes the contact between the carbon lining and the cable much more effective.

A certain amount of hydrofluoric acid is evolved from the cryolite used. The metal from the furnace is remelted, and the pure metal, free from mechanical admixture, is poured into ingots.

* *Metallurgie*, 1910, vol. vii. p. 596.
† *Electrical Review*, January 20, 1911, vol. lxviii. p. 99.

Water power is used, and the alumina is purified from bauxite by the Bayer process. The bauxite is kilned, pulverised, and mixed with caustic soda solution, 40 per cent. strength. After treatment with this solution it is filter-pressed and the filtered aluminate of soda is treated in tanks with previously precipitated alumina. After some time the alumina is precipitated as a white semi-flocculent substance, which is washed, dried, and calcined at a cherry-red heat.

Oxidising Roast of Calcium Sulphide.—The metallurgical aspects of the reduction of calcium sulphate by carbon monoxide and carbon and the oxidation of calcium sulphide are dealt with theoretically and practically by H. O. Hofman,* with special reference to the behaviour of calcium sulphide when subjected to an oxidising roast in pure dry air. The experiments and observations recorded tend to show that in melting an oxide ore with gypsum as flux in the blast-furnace the matte to be produced must be formed mainly in the upper part of the furnace, by reactions taking place while the charge is still solid ; lower down, when the matte begins to fuse, it will trickle through the slag that is still forming, and then join the melted slag. During its downward passage it will change in composition, becoming richer in the available metal that has a stronger affinity for sulphur.

Gypsum is desirable as a sulphurising flux only with fusions in which there is an objection to the use of pyrite, which, with its sulphur, adds iron, and usually some copper, arsenic, antimony, &c., to the charge. Further disadvantages of gypsum are that it requires special reducing blast-furnace conditions, and that it consumes considerable amounts of carbon for its own reduction to calcium sulphide.

* *Bulletin of the American Institute of Mining Engineers,* November 1910, p. 917.

ELECTRO-METALLURGY.

CONTENTS.

I.—*ELECTRIC SMELTING.*

Behaviour of Copper Slags in the Electric Furnace.—L. T. Wright * points out that ferruginous copper furnace slags, if fused in the electric arc, will yield metallic iron containing copper.

In practice a very large amount of metallic iron can be thus produced, and this iron carries with it practically all the copper, gold, and silver, and more than 50 per cent. of the sulphur, of the original slag. The metallic buttons formed in the electric furnace are clean, hard, and not brittle.

Electric Reduction of Tin Dross.—A method for the reduction of tin dross is described by R. S. Wile.† Electrical heat was resorted to because the heat could be applied to the slag at the bottom of a shaft furnace, thus enabling the dross to be thrown on top of the slag, instead of being mixed with it, as in the old style of treatment. The dross, being on the top, only comes in contact with the slag at the point of reduction. The liberated gases filter through the dross, while any tin oxide volatilised is condensed in the cooler portion or the dross. In operating the furnace, the top carbon, which is movable, is brought into contact with the lower stationary carbon, and an arc is formed ; the slag is charged and melted, and the carbon is raised until the desired amount of slag is added. The dross mixed with the correct amount of carbon is charged, and the resulting tin is tapped from the bottom from time to time. The average loss of tin is less than 1 per cent. The furnaces are 20 inches in diameter and 80 inches high inside. They consume about 44 kilowatts. During the run the amperage should be kept

constant, the voltage varying. At the start the voltage is about 80, but towards the end drops to 45 or 50.

Electric Melting of Copper.—In a letter to the Editor, C. A. Hansen * calls attention to the danger of copper-poisoning during the electric melting of copper. A charge of 5000 pounds of electrolytic copper scrap—uncontaminated except for a small amount of admixed iron—was melted down in a three-phase arc furnace of the ordinary steel furnace type, the experiment lasting about five hours.

A few hours after pouring off all the ten men engaged in the furnace building suffered inconvenience in breathing. For the ensuing hours severe nausea was experienced in each case, and a soreness throughout the entire system, similar to that of acute grippe.

As the run resembled an ordinary steel run, the trouble is attributed to the presence of copper shown to be present in the furnace fumes.

The temperature of the copper bath as a whole at no time exceeded 1300° C., so that probably the copper was volatilised only at points directly beneath the electrodes. During five years of continuous research work on a large scale with furnace processes, which involved, among others, tellurium, telluride, arsenic, arsenides, zinc, and sulphide ores, the only other physical inconvenience suffered has been an occasional carbon monoxide headache.

Electrolytic Chromium.—J. Voisin † deals with the electrolytic production of chromium, and gives a short account of the history of previous investigations on the subject, and the result of his own experiments, which were carried out according to the methods devised by Placet, Férrée, and Carveth respectively. He emphasises the need for maintaining the concentration of the electrolyte by using soluble anodes of chromium. Alumino-thermic chromium, and chromium obtained in the electric furnace, are equally as satisfactory as anode materials, although the latter has a tendency to disintegrate more rapidly. The electrolytic operations were carried out in chromic baths, in baths of chromium fluoride, and in baths of chromous salts. In the latter case chromous sulphate was used, the bath being prepared by dissolving chromous acetate in weak sulphuric acid, the anode being of chromium and the cathode of platinum, with a current density of 7·5 amperes per square decimetre, and end pressure of 10 volts. A white compact deposit was obtained, the yield of metal amounting to 70 per cent.

Electro-Metallurgical Smelting of Copper.—W. Borchers ‡ deals with the progress of refining processes and methods of concentration in the metallurgy of copper, and their simplification and shortening by electric smelting. Fine ores, such as the calcination products of fine copper ores, can be treated in the electric furnace without any preliminary briquetting, and the conductivity of most of the ores and mattes

* *Metallurgical and Chemical Engineering*, February 1911, vol. ix. p. 67.
† *Revue de Métallurgie*, 1910, vol. vii. p. 1137.
‡ *Ibid.*, p. 1126.

of copper is such that they can be placed as resistances within the circuit. They may therefore be worked either in the form of an extended column, or in long hearths, with the result that the reactions consequent on the reduction of the metal from its oxides and sulphides, as well as the formation of slag, take place without the unfavourable influence of furnace gases, which are sometimes of an oxidising and sometimes of a reducing nature. Another advantage arises from the fact that only the gas from the sulphur dioxide reaction (carbon dioxide), in the presence of carbonates, is evolved. Thus the volume of the gas is much less than in reverberatory furnaces, which diminishes the losses by evaporation and by the mechanical carrying-off of dust. Slags contain hardly any copper, and if the composition of the gangue is favourable to the scorification of the copper, that metal can be concentrated as a matte at the surface of the bath by the addition of raw ores.

II.—*ELECTRIC FURNACES.*

Flow of Heat through Furnace Walls.—The flow of heat through furnace walls is dealt with by F. T. Snyder,[*] who analyses the parts which heat convection and heat radiation play in compound furnace walls. The unit of heat-flow used is the temperature drop in degrees centigrade per inch of thickness per kilowatt per square foot. The radiation of heat from the outside surface varies with the difference between the fourth powers of the absolute temperature of the surface and the air, multiplied by a constant to reduce the results to kilowatts of heat-flow per square foot. The convection of heat from the surface is affected by two factors, the transfer resistance of the flow of heat from the surface to the air, and the movement of the heated air away from the surface. The radiation according to Stephan's law is

$$R = a\,(T^4 - t^4),$$

where R = kilowatts per square foot; T = hot temperature; t = cold temperature, and $a = 0.0033 \times 10^{-9}$ for ordinary sheet iron, and 0.0042×10^{-9} for brick and slag.

The convection of heat from the surface to the air as a function of the velocity of the convection currents is given by the formula

$$C = b\,(T - t)\,(2 + 5.5\sqrt{v}),$$

where C = kilowatts per square foot; T = temperature of furnace surface; t = temperature of air; $b = 0.00011$ for sheet-iron furnace shell or 0.00015 for brick furnace surface; v = velocity of convection currents in feet per second. The velocity of the convection currents is in turn determined by the temperature of the surface, and may be expressed by the following simple formula :—

$$v = 0.0022\,(T - t)^{\frac{3}{2}}$$

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[*] *Transactions of the American Electrochemical Society*, 1910, vol. xviii. pp. 235-253.

A set of data for different materials is given. Details are also given for the calculation of the heat-flow and temperature distribution for a proposed furnace wall, and a numerical example is added on the calculation of the temperature distributions through the bottom of a small steel furnace.

Formulæ for Pinch Phenomenon.—C. Hering * gives in various forms the formulæ necessary for calculating the internal electromagnetic force which acts in contracting the cross-section of a conductor, due to the current, and which is known as the pinch phenomenon. He also points out that the complete rupture of a conductor can take place long before this pinch pressure has reached the hydraulic pressure at the bottom of a trough. This must be taken into consideration in applying the formulæ given in the article.

The Electric Furnace and its Applications.—In a paper on the electric furnace and its applications, M. Ruthenburg † briefly traces its history from the first electric furnace built by Siemens thirty-five years ago. Alternating current is preferred in all electric furnaces in which a heating effect only is required, direct current being used only in cases where an electrolytic action is required, as in manufacture of aluminium.

To prevent the waste of electrodes, which represents a great expense, water-jackets are advocated, as is also the use of slag as a conductor of heat.

Various applications of the electric furnace are reviewed, especially in the treatment of nickeliferous iron ores; complex lead-zinc-iron ores, in the smelting of which lead and zinc are volatilised and condensed outside; tin ores; ores of tungsten, manganese, &c.

III.—*ELECTRO-REFINING.*

Electro-Refining of Copper.—The results of experiments carried out at Lithgow, New South Wales, on the purification of electrolytes, are given by H. Schroder.‡ The old method consisted in withdrawing a portion each day and evaporating in lead-lined tanks by means of hard lead coils in the bottom, heated by exhaust steam from the engines. The solution was evaporated to a specific gravity of 1·4, and whilst still hot was syphoned into crystallising tanks, where the copper sulphate was crystallised on sheets of lead. The resulting solution was again evaporated and crystallised, but a third treatment was not possible owing to the impurity of resulting crystals, therefore the remaining copper was extracted by running over iron. The waste liquor was discarded, and much sul-

* *Metallurgical and Chemical Engineering*, February 1911, vol. ix. pp. 86–87.
† Paper read before the Chicago Meeting of the American Electrochemical Society. Abstract in *Metallurgical and Chemical Engineering*, November 1910, vol. viii. p. 635.
‡ *Australian Mining Standard*, December 28, 1910, vol. xliv. pp. 659–660; January 4, 1911, vol. xlv. pp. 7–8.

phuric acid was lost by this method. The cement copper obtained was dried, roasted, and gradually worked up by charging in small lots into the refining of pigs of crude copper.

The elimination of arsenic was found to be imperfect, and most of it found its way back to the copper anodes. Roasting the cement copper was found to eliminate only 30 per cent. of the arsenic.

Experiments were investigated by G. H. Blakemore on the use of insoluble anodes, the object being to purify the electrolyte, and at the same time to produce the least possible quantity of impure copper.

A portion of the electrolyte was drawn off and circulated through a series of tanks fitted with lead anodes to reduce the copper content, but the flow was so regulated that the solution leaving the last tank contained sufficient copper (7 per cent.) to precipitate pure metal. This liquor was passed into a second series of tanks provided with insoluble anodes, and in which there was no circulation. The current was passed, and in eight to twelve days all the arsenic and bismuth was deposited, the cathodes being black and the deposits fragile. The loose deposit brushed off the cathodes contained 71 per cent. copper, 3·5 per cent. arsenic, and 1·6 per cent. bismuth, and the cathodes contained 98·2 per cent. copper, 0·18 per cent. arsenic, and 0·25 per cent. bismuth.

The copper contents of the bath were reduced to 1·8 per cent. copper sulphate, and remained stationary at that. The purified solution was returned to ordinary circulation with the main bulk of electrolyte.

The experiments were stopped owing to the shutting down of the plant, but proved the following points :—

(1) Using a current density of 7 amperes per square foot of cathode surface, the solution containing 7 per cent. copper sulphate ($CuSO_4,5H_2O$), and with free acid up to 14 per cent., the cathodes darken, and bismuth and arsenic begin to deposit.

(2) Using the same current density in a non-circulating solution, with insoluble anodes, arsenic was removed very regularly. Starting with 0·54 gramme arsenious oxide per litre, it required about twelve days to reduce it to 0·15 gramme, whereas most of the bismuth was removed during the first two days, and the solution never got below 2 per cent. copper sulphate.

When using a current density of 14 amperes, it was found that the solution could be reduced to 1·7 per cent. copper sulphate, and that the arsenious oxide was reduced from 0·54 gramme per litre to 0·015 gramme in six days.

The suggestions made are that the copper contents of the electrolyte be lowered in lead anode tanks with circulating liquor to the safety mark before treatment in tanks using non-circulating liquor. The whole of the impurities would then be concentrated in a small amount of copper, and if this was well worked in a roaster with a small amount of matte, a good deal of arsenic would be eliminated, and if this matte was blown in a converter, there would be little arsenic to get back to the tank-house. Or anodes from the melting of the impure copper cathodes and slimes could be treated in a separate tank, and the cathodes so produced removed

as long as they remain pure. The resultant liquor could be concentrated and crystallised, and the final copper removed on metallic iron.

Electro-Refining of Gold.—A recently patented development of the Wohlwill process for the refining of gold * is described, by which the process, hitherto only applicable to the refining of gold containing less than 6 per cent. of silver. may now be applied to the parting of Doré bars and similar mixed gold alloys. The improvement is effected by the use of asymmetrical alternating electric currents instead of direct currents. preferably produced by connecting a source of direct current and a source of alternating current in series. In refining gold alloys containing a material percentage of lead, the addition of sulphuric acid to the bath is suggested.

IV.—*ELECTRO-DEPOSITION*.

New Method of Metal Coating.—A new method of coating various substances with metal † consists in reducing the metal to be deposited to a state of pulverisation by the pressure of an inert gas—nitrogen or hydrogen—and in that state driving it against the surfaces to be covered. The apparatus consists of a closed crucible with an orifice at the bottom opened and closed by a valve worked from outside. The inert gas is supplied from the usual compressed cylinder, and is pre-heated to 200° F. by leading through a gas furnace beyond which it divides into two branches : one of these branches is led into the crucible, producing a pressure which extrudes the metal from the bottom orifice and through a suitable tube. the outlet of which meets the other branch of the preheated nitrogen or hydrogen tube. The result of the mingling of the two jets of inert gas and molten metal under these conditions is said to be the production of a cloud of metallic vapour, which, projected against a surface of almost any substance, forms upon it a metallic coating similar to the deposit of copper on an electrotype plate by the galvanic process.

Silver Plating, &c.—Measurement of Deposits.—It has been proposed to provide the ampere-hour meter ‡ with a scale marked in pounds of copper, ounces of silver, or units of any other plating metal, so that when the meter is placed in series with an electroplating bath the exact quantity of metal deposited can be read directly without examining the plated piece. The ampere-hour meter hand is arranged with a set-back attachment. so that it can be started from zero at the beginning of each plating operation. It is stated that the reading of the meter has in practice attained an accuracy, with large batches of work. in the electroplating baths of 99·5 per cent. of the actual deposits by weight. A contact piece on a movable hand makes it possible to operate a circuit-breaker and stop the plating operation after a given weight of metal has been deposited.

* *Brass World*, August 1910, vol. vi. p. 281.
† *Metal Industry*, March 1911, vol. iii. p. 123.
‡ *Electrical Review*, March 17, 1911, vol. lxviii. p. 455.

THE PROPERTIES OF METALS AND ALLOYS.

CONTENTS.

I.—*COMMON METALS.*

Corrosion of Aluminium. — Experiments on the corrosion of aluminium sheets and vessels have been carried out by E. Heyn [*] and O. Bauer, and show that two kinds of corrosion, one general and the other local, occur. The greater the cold work put on the metal, the greater is the tendency to local corrosion, whilst after annealing at 450° water and solutions give rise only to general corrosion. The destruction of aluminium vessels is generally due to local corrosion, and the lines of corrosion often indicate clearly the direction of the original cold working. Greasing aluminium vessels with vaseline when stored in air is recommended, and it is also recommended that such vessels should, whenever possible, be annealed at 400° to 450° in order to remove all traces of cold work.

II.—*RARE METALS.*

Native Gold.—A beautifully crystallised specimen of native gold from Moresby Island, British Columbia, is described by R. P. D. Graham.[†] It occurs as a cluster of crystals attached to colourless quartz. The largest crystal is 4 by 3 mm., and all are very sharp and brilliant. The surfaces are striated and show re-entrant angles, apparently due to oscillatory repetition of the faces of the normal octahedron. A further attempt is now being made to work the Gold Harbour Mine in this neighbourhood.

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[*] *Mitteilungen königlichen Materialprüfungsamt,* 1911. vol. xxix. p. 2.
[†] *American Journal of Science,* 1911, vol. [iv.] xxxi. p. 45.

Notes on the Chemistry and Metallurgy of Vanadium.—The chemistry of vanadium, vanadium analysis, and some new metallurgical methods connected with this metal are dealt with by W. F. Bleecker.* The various methods of preparing the metal are given, and some properties of the resulting product. The properties of vanadic acid are given in detail, and also the properties of those compounds of vanadium which are of importance in metallurgical operations or incident thereto. The metallic vanadates, which are formed in general by the addition of a soluble salt of a metal to a neutral solution of sodium or potassium vanadate, receive special attention, as these are not discussed in previously published papers.

Of these the most important is vanadate of iron, which is a general name given to the ortho, meta, pyro, and tetra vanadates, and also to a mixture of one or more of these with ferric or ferrous oxide. Vanadate of copper is also of considerable metallurgical importance. The vanadates of mercury, zinc, silver, gold, calcium, aluminium, and lead are also discussed. It is pointed out that it is very necessary to have uniform conditions in work with vanadium, as slight changes in conditions cause the formation of salts in different degrees of oxidation.

Possibilities in the Use of Rare Metals in Alloys.—The results that have been obtained in steel by the use of nickel, tungsten, vanadium, molybdenum, titanium, chromium, and other so-called rare metals, serve to indicate that the possibilities are equally as great in the manufacture of the non-ferrous alloys. † The field is, perhaps, even larger and the possibilities greater than in the ferrous alloys.

Zirconium is now proposed as a deoxidising agent. Vanadium is useful in the manufacture of babbitt metals, inasmuch as it produces clean scrap material when melted. Chromium has already been used in the manufacture of strong bronzes. Only a beginning has been made however, and it is believed that the future will see remarkable products evolved through the agency of certain of the rare metals.

It is remarkable and also interesting to note the change in character of the so-called rare metals and their transition from the " rare " to the " common " classification. Titanium, chromium, tungsten, and some of the other metals have, in the past, been called rare for the reason that they were seldom reduced to the metallic state. The ores, however, are more or less common, and through the agency of the electric furnace and the alumino-thermic process, their reduction from the oxides is a simple matter, and it is now possible to obtain them in large quantities at a comparatively low price.

An alloy of iron and cerium possesses the property of emitting sparks when struck, and it is this alloy which is used in self-lighting match boxes. Before this fact was discovered cerium was only a curiosity, and no use for it was known.

Tantalum was also a metal unused until it was found that it could be drawn into wire and employed as electric light filaments.

Radium.—Metallic radium has now been prepared by Mme. Curie [*] and A. Debierne. They employed the method of Guntz, of Geneva, according to which an amalgam of the metal in question is prepared, and the mercury removed by distillation. They electrolysed an aqueous solution of 0·106 gramme of pure radium chloride, with a cathode of mercury (10 grammes), and an anode of platinum-iridium. The resulting amalgam was liquid (it would be crystalline in the case of barium, to which radium is related); it was quickly dried and distilled in an iron boat within a quartz tube in a hydrogen atmosphere, because it began to spurt in a vacuum. Most of the mercury having been distilled off at 270° C., a brilliant white metal, melting sharply at 700° C., was left. At higher temperature it volatilised, and attacked the quartz tube energetically. Exposed to the air it turned black, probably forming a nitride; a speck of the metal falling on a paper produced a mark like that of a burn. The radium decomposed water, forming a soluble hydrate like the alkali metals. Its radioactive behaviour was as expected.

III.—*ALLOYS.*

Alloys for Permanent Magnets.—Results are given of an investigation on the magnetic properties of electrolytic iron and its alloys by C. F. Burgess [†] and J. Aston. The tests are for the most part on carbon-free alloys, and the results indicate the influence of the added elements in inducing the conditions necessary for good permanent magnets. The bars were tested as forged, and also after water quenching at 1000° C. The alloys examined, and of which results are recorded, include chromium, manganese, molybdenum, nickel, and tungsten as binary alloys, or in various combinations together, or with other elements.

From the results it may be deduced that chromium, manganese, molybdenum, and tungsten are the important additions in the manufacture of steel for permanent magnets, but the presence of some third element is necessary. While carbon is beneficial, it is possible to obtain highly satisfactory material, either by various combinations of the above four elements, or by suitable additions of silicon or vanadium.

Alloys of Cadmium, Bismuth, and Lead.—The equilibrium in these ternary alloys, investigated by W. E. Barlow, [‡] is of a simple type, there being three freezing-point surfaces, with a ternary eutectic point at 91·5°, the composition of the ternary eutectic being 40·2 per cent. of lead, 51·65 per cent. of bismuth, and 8·15 per cent. of cadmium.

Amalgams of Silver and Tin.—The amalgams of silver and tin have been studied in some detail by R. A. Joyner, [§] with a view to

[*] *Comptes Rendus*, September 5, 1910, vol. xv. p. 737.
[†] *Metallurgical and Chemical Engineering*, December 1910, vol. viii. pp. 673–676.
[‡] *Journal of American Chemical Society*, 1910, vol. xxxii. p. 1390.
[§] *Journal of the Chemical Society*, 1911, vol. xcix. p. 195.

explaining the remarkable changes occurring in dental amalgams. Alloys of tin and silver containing less silver than the compound Ag_3Sn are heterogeneous, and contain eutectic. The "ageing" of these alloys is shown by the quantity of mercury immediately taken up being only half that absorbed by the unaged alloy. Ageing may be brought about by time, or by heating above 100° if filings are used, but bars of metal do not undergo the change. It is shown that mechanical strain does not account for the difference, and the property of ageing must be a characteristic of the compound Ag_3Sn. The quantity of mercury which ultimately unites with the alloy is the same for aged as for unaged filings, but the rate of amalgamation is very different.

Ternary alloys of tin, silver, and mercury have been examined up to 63°, analyses of the liquid phase being made after straining through cotton wool.

Bearing Metals.—An extensive investigation of bearing metals, particularly those employed on railways, has been undertaken by E. Heyn [*] and O. Bauer. The experiments with white metals having a tin base show that remelting causes a slight loss of both tin and antimony, so that the proportion of copper rises. After five times remelting, however, the change in structure and in mechanical properties is almost inappreciable. The rate of cooling of the casting has a far greater influence, rapid cooling increasing the hardness and the resistance to pressure and shock. The relative qualities of castings of similar composition may be judged approximately by the appearance of the fracture, better by microscopical examination.

The addition of aluminium or magnesium as deoxidisers increases the hardness slightly, without otherwise altering the properties if only small quantities are added, but the addition appears to be unnecessary. The principal requirements for success are casting from a sufficiently low temperature and rapid cooling.

A similar series of experiments with bearing bronzes shows that chill castings are better than sand castings, being stronger, harder, and less porous. By regulating the rate of cooling, castings of alloys low in tin may be made to give results equal to those usually obtained from the more expensive bronzes high in tin. Remelting has little effect on the hardness, the compressive strength, or the analysis; but the tin oxide, which is formed by oxidation, remains enclosed in the alloy, and diminishes its tensile strength and resistance to shock. Rapid cooling from above 782° is favourable. Arsenic is without effect on the casting qualities up to 1·52 per cent. Chill castings are hardened by arsenic, without any change of structure. Resistance to shock is increased by arsenic when this exceeds 0·65 per cent.

Chromax Bronze and its Properties.—J. Naulty [†] and J. Scanlin have discovered that 5 per cent. of chromium added to an alloy of

[*] *Mitteilungen königlichen Materialprüfungsamt*, 1911, vol. xxix. pp. 29, 63.
[†] *Brass World*, October 1910, vol. vi. p. 357.

copper, nickel, and zinc produces a strong and non-corrosive mixture, which may be used for a variety of purposes, and will take an edge sufficient for cutting tools. It is white in colour, and takes a high polish. Its toughness is that of cold-rolled shafting. It resists the action of salt water and of acids to a marked degree. Tests of sand castings showed a tensile strength of 78,950 lbs. per square inch. Tested for its qualities as a bearing metal over 363 actual running hours, it is stated to have shown a variation of only 0·001 of an inch. The weight on the bearing was 30 lbs.—that is, the valve springs weighed 30 lbs.—on a $\frac{1}{4}$-inch lift, which, while running 1750 revolutions per minute, caused 7000 blows on the bearings per minute.

Cobalt-Gold Alloys.—The equilibrium diagram of cobalt-gold alloys has been investigated by W. Wahl,* who has studied these alloys by thermal and microscopical methods, and in their magnetic and crystalline aspects. Alloys of cobalt, together with the pure metal, exhibited to a marked extent the phenomenon of supercooling. The supercooling appears to increase in proportion to the pureness of the metal, and in one experiment amounted to no less than 200° C. The melting-point of the eutectic is 997°, at which point the alloy contains 90 per cent. of gold.

Conductivity of Liquid Alloys.—The method of determining the electrical conductivity of alloys in the molten condition is described in detail by P. Müller,† the results of whose determinations have been described previously (this Journal, vol. iii. p. 305). The method consists in measuring the fall of potential between two platinum points sealed into a glass tube, or (when silica tubes are used) enclosed in thin silica tubes, reaching to suitable distances in the outer tube containing the alloy. The whole is heated in a specially arranged electric furnace. A current of about 9 amperes is passed through the alloy, connection being made by means of platinum wires, and the fall of potential between the intermediate electrodes is measured by means of a millivoltimeter.

Copper-Tin-Lead Alloys.—The ternary system copper-tin-lead, in which the lead bronzes occur, has been investigated by F. Giolitti and M. Marantonio.‡ The alloys investigated contained 0·0 to 20 per cent. of lead, and 0·0 to 25 per cent. of tin. In the binary system copper-lead, no compounds are formed, the components being incompletely miscible in the liquid and unmiscible in the solid states. The temperature of the eutectic is practically identical with the melting-point of lead. In the ternary alloys, on the other hand, the tin exists either as Cu_4Sn or Cu_3Sn. Experiments were also carried out on the hardness of the alloys of these metals.

* *Zeitschrift für anorganische Chemie*, vol. lxvi. pp. 60–72 ; *Journal of Royal Microscopical Society*, 1910, p. 525.
† *Metallurgie*, 1910, vol. vii. p. 730.
‡ *Gazzetta Chimica Italiana*, vol. xl. p. 51 ; *Journal of Royal Microscopical Society*, 1910, p. 526.

Corrosion of Copper Alloys.—A specimen of delta metal corroded by sea water was found by W. P. Jorissen * to have lost the whole of its zinc, and to contain 41 per cent. of cuprous oxide. When copper, partly immersed in water, is corroded, cuprous oxide is formed on the submerged and cupric oxide on the exposed part.

Gold-Palladium Alloys.—Gold and palladium form a continuous series of solid solutions, and it is found by Wilhelm Geibel † that the electrical conductivity and its temperature-coefficient sink to minimum values near to 40 atomic per cent. of gold, whilst the tensile strength is a maximum for the 60 per cent. alloy, and the thermo-electric power, measured against platinum, has the greatest negative value for the 45 atomic per cent. alloy. It is found that a couple composed of a gold wire and a wire of a 60 per cent. gold, 40 per cent. palladium alloy has about six times as great a thermo-electric electromotive force as a platinum-rhodium couple. Unfortunately, its usefulness is limited by the liability of palladium alloys to undergo disintegration.

Heusler Alloys.—The electrical conductivity and thermo-electric power of these alloys have been investigated by F. A. Schulze.‡ The conductivity increases with the length of the ageing process until a maximum is reached, and the thermo-electric power varies in the same manner, a minimum value of each, however, being observed when ageing is carried out at 225°. There is an intimate connection between these properties and the magnetic susceptibility.

A number of further studies of the Heusler alloys have appeared. A. A. Knowlton § finds that sound alloys are best obtained by casting in hot graphite moulds, and avoiding the presence of silica in the crucibles. The relation of the electrical and magnetic properties to the crystalline structure was also studied. The value of the magnetisation I at saturation appears to be proportional to the size of the crystals of the principal constituent. It was not found possible to detect any heat-change on passing from the non-magnetic to the magnetic state.

Lead-Tin-Antimony Alloys.—The ternary alloys of lead, tin, and antimony, so frequently employed as bearing metals, have been studied fully by Richard Loebe. ‖ Lead does not form compounds or solid solutions with the other metals, and the crystals separating are thus the same as in the binary alloys of tin and antimony. There is no ternary eutectic, and the eutectic-like structure characteristic of these bearing metals is composed of lead and one or other of the tin-antimony solid solutions, separating along a line of equilibrium between two solid phases. The most fusible alloy of the whole series is the eutectic of lead and tin. The alloys are very liable to segregate during solidi-

* *Zeitschrift für angewandte Chemie*, 1910, vol. xxiii. p. 2305.
† *Zeitschrift für anorganische Chemie*, 1910, vol. lxix. p. 38.
‡ *Berichte der deutschen physikalischen Gesellschaft*, 1910, vol. xii. p. 822.
§ *Physical Review*, 1911, vol. xxxii. p. 54.
‖ *Metallurgie*, 1911, vol. viii. pp. 7, 33.

fication, on account of the great difference in specific gravity between the crystals and the mother liquor. Exact investigation of the thermal changes is difficult, owing to the slowness with which equilibrium between the phases is reached.

Magnesium-Aluminium Alloys.—The electrical, thermo-electric, and electrolytic properties of alloys of magnesium and aluminium are found by W. Broniewski * to show abrupt discontinuities at the composition corresponding with Al_2Mg_3. The author also considers that the curves justify the assumption of a second compound, AlMg, but no other compound is found.

Monel Metal.—J. F. Thompson † describes the properties of Monel metal, which is a natural alloy of nickel and copper. The ore from which the metal is derived comes from the mines at Copper Cliff, Ontario. In this alloy nickel predominates, constituting about 58 per cent. It also contains some iron and small percentages of other materials introduced in the furnace. The metal has proved exceedingly satisfactory for large castings such as battleship propellers, of which several have been made for the United States Navy and also for battleships built for the Argentine Republic and for Japan. Tensile tests show Monel metal to possess an elastic limit of 58,873 lbs. per square inch, with a breaking strength of 86,899 lbs. per square inch ; 40 per cent. elongation, and 60·5 per cent. reduction of area in the case of hotrolled rods, an elastic limit of 37,427 lbs. per square inch, a breaking strength of 78,236 lbs. per square inch ; 38·5 per cent. elongation, and 34 per cent. contraction of area, in the case of sand castings. The melting point is given as 1360° C., and the specific gravity of cast Monel metal as 8·87. One of the chief causes of the efficiency of the metal for screw propellers is its modulus of elasticity, which is 22,000,000 to 23,000,000. It also resists corrosion, and will take and retain a high polish.

New Alloy.—A new light alloy called "Atherium," ‡ which has some remarkable properties, has recently been put on the market. It is lighter than aluminium, having a specific gravity of 2·4 to 2·57. On a test-piece 0·628 inches in diameter, this alloy has shown an elastic limit of 33,712 lbs. per square inch, an ultimate strength of 41,798 lbs. per square inch, an extension of 17·5 per cent. measured on 2 inches, and a reduction of area of 39·1 per cent. The alloy makes sound castings, and rolls and turns well. It can be soldered, forged, and welded, and does not tarnish or corrode. The conductivity is about 55·1.

"Ruebel" Bronze.—W. Ruebel § is stated to have invented an alloy of magnesium with an aggregate maximum of 10 per cent. of zinc,

* *Comptes Rendus*, 1911, vol. clii. p. 85.
† *Engineering and Mining Journal*, vol. xci. p. 223.
‡ *Electrician*, January 13, 1911, vol. lxvi. p. 525.
§ *Metal Industry*, August 1910, vol. ii. p. 273.

copper, and aluminium. Magnesium is said to lose its bad qualities when alloyed with even this small percentage of other metals, and to combine low specific gravity with high resisting power. It is stated that the use of this alloy would reduce by from $3\frac{1}{2}$ to 4 tons the weight of a Zeppelin airship.

Season-Cracking of Brass Tubing and Sheet by Ammonia.— The influence of ammonia on brass is described,* and it is pointed out that the presence of ammonia may be due to its evolution from organic matter. There are two illustrations, one of seamless brass tubing showing the effect of ammonia, and one of a brass acetylene generator which season-cracked owing to ammonia generated by the calcium carbide.

Silicon Alloys of Non-Ferrous Metals.—L. Baraduc-Muller † discusses the constitution of metallic silicides, and the action of carbide of silicon on various metallic oxides. He also gives a list of the silicon alloys, with a historical sketch relating to their discovery and investigation. The alloys thus dealt with are those of silicon-antimony, silicon-silver, silicon-bismuth, and silicon-tin, silicon-gold, silicon-lead, silicon-potassium, silicon-thallium, and silicon-zinc. By the action of silicon carbide on oxides of the metals he has succeeded in producing numerous other alloys, such as silicon-cobalt, silicon-copper, silicon-iron, silicon-chromium, and alloys of iridium, lithium, manganese, molybdenum, palladium, platinum, ruthenium, strontium, tantalum, thorium, titanium, tungsten, uranium, vanadium, and zirconium. Special investigation has been made on the expansion of the silicon alloys on heating from 15° C. to 1000° C. The conclusions derived from these investigations are that the dilatation of any alloy should be expressed by at least four curves—a curve for the alloy as cast, a curve for the alloy as quenched, and curves for both classes after annealing. If the annealing has been carried out at the right temperature for the cast and quenched test-pieces, the cooling curves of all four categories should merge into a single curve, the heating curves of the quenched cast and annealed test-pieces differing amongst themselves. If on casting or on quenching profound and distinctive internal modifications are produced, the cooling curves will not tend to merge into a single curve, but there will be two curves corresponding to two different states of equilibrium. A systematic investigation carried out on these principles enables the exact influence of the temperatures of successive quenchings and of the influence of the duration and temperature of annealing to be ascertained, and it further indicates the temperature at which the influence of annealing commences, and can therefore, with the help of metallography, yield most useful indications.

Silver-Cadmium Alloys.—The alloys of silver and cadmium have been more fully investigated by G. J. Petrenko ‡ and A. S. Fedoroff,

* *Brass World*, August 1910, vol. vi. p. 269.
† *Revue de Métallurgie*, 1910, vol. vii. p. 585.
‡ *Zeitschrift für anorganische Chemie*, 1911, vol. lxx. p. 157.

who find a complicated system. Six series of solid solutions are recognised as being formed from the liquid, α, β, γ, δ, ϵ, and η, the gaps between them being 7-19, 31–34, 39–43, and 57–64 per cent. of silver. At 200° a reaction takes place between the α and γ solid phases, resulting in the formation of the compound AgCd, which is only stable below that temperature. The form of the freezing-point curve indicates that the solid solutions may contain compounds $AgCd_4$, $AgCd_2$, and Ag_2Cd_3, the last having a pink colour, whilst AgCd is grey.

Silver is more volatile when mixed with cadmium, so that there is a loss of both cadmium and silver on remelting, and it is necessary to analyse each alloy after taking its cooling curve.

Sodium-Silver Alloys.—According to E. Quercigh,* sodium does not react appreciably with silver below 700°. After heating to this temperature, separation into two layers does not take place. The eutectic point lies close to the sodium end of the curve. Silver holds up to 13 atomic per cent. of sodium in solid solution.

The alloys of sodium and silver have also been examined by C. H. Mathewson † with very similar results. Silver is found to crystallise very well from its solution in sodium, branched groups of octahedra being obtained, closely resembling native silver. From dilute solution it frequently crystallises in perfectly formed single octahedra, whilst other crystals show twinning on the spinel type.

Sodium Tellurides.—The thermal analysis of mixtures of sodium and tellurium shows, according to G. Pellini ‡ and E. Quercigh, that only three compounds are formed, namely, Na_2Te, Na_2Te_2, and Na_2Te_5, of which only the first melts without decomposition. It is white, but readily alters in air; the other two compounds are grey and metallic.

Tellurides of Cadmium and Tin.—Tellurium forms only a single compound with cadmium and tin respectively, namely, TeCd and TeSn. The freezing-point curve, as shown by Matsusuke Kobayashi,§ is marked in each case by a maximum, and solid solutions are not formed. Cadmium telluride melts at 1042°, and tin telluride at 780°.

Tellurides of Silver and Gold.—The compounds of tellurium and silver have been studied by G. Pellini ‖ and E. Quercigh. Two compounds only exist, Ag_2Te, melting at 959°, and AgTe, which melts and decomposes at 444°, and undergoes a polymorphic change at 412°. The first compound is identical with the mineral hessite. The other silver-tellurium minerals are probably mixtures. The alloys diminish regularly in brittleness from tellurium to silver.

The gold-tellurium curve has also a single maximum at 464°, corre-

* *Zeitschrift für anorganische Chemie*, 1910, vol. lxviii. p. 301.
† *Internat. Zeitschrift für Metallographie*, 1911, vol. i. p. 51.
‡ *Atti Reale Accademia dei Lincei*, 1910, vol. [v.] xix. ii. p. 350.
§ *Zeitschrift für anorganische Chemie*, 1910, vol. lxix. p. 1.
‖ *Atti Reale Accademia dei Lincei*, 1910, vol. [v.] xix. ii. pp. 415, 445.

sponding with the compound AuTe₂, identical with the natural mineral calaverite, which must have been formed by fusion, as it is not obtained in the wet way. Solid solutions are not formed.

Tests of Acid-Resisting Alloys.—Details are given by A. M. Fairlie * of some physical and chemical tests of acid-resisting alloys. Various lead-antimony and lead-nickel alloys were tested to show their relative strength, ductility, and acid-resisting properties. The strongest alloy was found to be that containing 90 per cent. lead and 10 per cent. antimony; and its acid-resisting qualities are almost equal to those of any other lead-antimony alloy. The nickel alloys possess superior acid-resisting properties, but a tensile strength less than half that of the best lead-antimony alloys.

The Thermal Diagram.—Although many metals are commonly regarded as completely immiscible in the solid state, it is known that they must possess a definite, although small, miscibility. It is shown by K. Bornemann † that this principle applies also to intermetallic compounds, which must form solid solutions, although probably to a small extent only, with both of their compounds. The modifications which are thereby introduced into the thermal diagram are discussed and illustrated by reference to the nickel-sulphur system.

IV.—*MISCELLANEOUS.*

Annealing of Copper, and Diseases of Copper.—The conditions to be observed during the annealing of copper are dealt with by F. Johnson,‡ who classifies these conditions as follows :—

(1) *Correct Temperature.*—A bright red heat, 900° C., is not too high for the purest copper, and impure copper of the refined type should also easily stand the temperature. The danger of raising copper to too high a temperature during annealing lies in the occurrence of incipient fusion, and is much intensified if gases of a reducing nature be present. If the annealing temperature be too low, then crystalline readjustment is not complete.

(2) *Atmosphere of Furnace.*—This must be carefully watched, and gases of a reducing action kept away from the copper, the action of such gases being to remove the all-important oxygen present.

(3) *Foreign Material in Furnace.*—There should be no sharp grit nor other foreign material on the floor of the annealing furnace, which must be kept perfectly clean. Brass articles should never be annealed in the same furnace and at the same time as copper articles.

(4) *Uniformity of Heating.*—This is of extreme importance, and every

* *Metal Industry*, February 1911, vol. iii. p. 64.
† *Metallurgie*, 1910, vol. vii. p. 740.
‡ *Metallurgical and Chemical Engineering*, February 1911, vol. ix. pp. 87–90.

portion of the article should be brought to a red heat. The closed type of annealing furnace is preferable.

(5) *Duration of Annealing.*—There is no advantage in prolonging the duration of annealing beyond the attainment of a uniform red heat.

(6) *Method of Cooling.*—Copper may be quenched from a bright red heat, or cooled slowly.

Quenching removes the scale, softens the metal, and toughens it against alternating stresses. Under diseases of copper, the author gives instances of corrosion by chemical action, the action of gases in the course of manufacture, and the action of gases in service. The abrading action of cinders, and the burning action of flame, are mentioned, cinders and flame being responsible for much of the wastage of stay-heads and scoring of fire-box plate. The presence of impurities in wrought copper may be considered as helpful, if anything, in enabling the copper to resist corrosion.

Corrosion of Metallic Food Containers. — The corrosion of metallic food containers is dealt with by E. Gudeman [*] in a paper read before the Chicago meeting of the American Electrochemical Society. Instances are given of samples of carbonated water containing from 0·00003 to 0·00005 per cent. of lead obtained by corrosion of the metallic button used to seal the bottles. The button used to hold the rubber caps averaged in new buttons about 18 per cent. of lead, whilst the old corroded buttons only contained 8 per cent. It was found that about twice as much lead as tin in the button went into solution. The solvent action of carbonated waters was found to be about the same on lead alloys as on the lead itself. Tin, copper, lead, silver, and iron are very soluble in the liquids used with canned food products and in the peculiar liquids produced in the decomposition of foods.

The two most commonly found products of decomposition are sulphuretted hydrogen and carbonic acid : the latter is a very strong corroding acid, especially when acting under pressure on metals in the presence of water, and food products placed in vacuum containers are less liable to deterioration.

Tin is a good protecting medium for iron under two conditions, viz. the coating must be perfect, and the contact between the tin and the iron must be perfect—conditions which are hard to fulfil. There are four main reactions that take place with food products due to the character of the foods themselves or to their decomposition under normal conditions of ageing. There is either oxidation or reduction, or both, and the action of acids or alkalies, or both. A perfect container will be one that will withstand all of these reactions. The author describes his process of impregnating iron articles with gold amalgam containing $\frac{1}{2}$ per cent. gold, and then heating to drive off the mercury. The amount of gold required to make a non-corrodible surface is only about 2 ounces per ton of iron, but the cost of such a plate will be twelve to fifteen times the cost of an ordinary tin plate. Experiments on other metals gave

very peculiar results ; for example, copper-sodium, obtained by impregnating copper with sodium amalgam, was found to resist the action of acids and water to a greater extent than copper, and antimony, impregnated copper, obtained by treating copper with antimony amalgam, greatly resisted the action of dilute nitric acid.

The author has also experimented on the impregnation of iron vessels with enamels at a pressure of 50,000 lbs. per square inch ; the superficial coating was then scraped off, and the vessel baked to melt the enamel.

These enamel-impregnated iron vessels withstood the action of acids and alkali as well as glass, but proved to be too expensive.

Experiments are also in progress for impregnating iron with hard glass.

Nucleus Action and Grain Growth.—H. M. Howe * examines the explanation given by E. Cohen † for the interesting cases of nucleus action in which tin which has been dulled in a certain way, when pressed against bright cold-worked tin, such as tinfoil, inoculates it with similar dulness, and that these infected spots thus caused can carry the infection to others, slowly at ordinary temperatures and more rapidly at higher temperatures.

It is pointed out that the initial bright state of tinfoil and tin plate is one of crystalline distortion or abnormal axing, the diseased state ; and the dulled state is one of cure, readjustment, or normal axing, in spite of the fact that here the cure is, as far as practical applications of tin are concerned, far worse than the disease. The question as to whether the crystalline distortion and readjustment may be considered to be the chief causes of the phenomena under the various conditions is examined.

The first case is that of the dulling of tin plate by reheating : simple exposure to 161°, 176°, and 184° did not cause dulling, though similar exposure when in contact with dulled tin did. In this case the molecular mobility caused by heating, and the nucleus action of dulled or normal axed crystals, jointly favour the readjustment or dulling of distorted crystals.

A second case is that careful oblique hammering on the bright surface of tin plate, so as to destroy the polish, sets up the dulling, which in turn dulls tinfoil pressed against it at 100°, setting up centres whence the dulling spreads. The action in this case becomes clear on the assumption that an exaggeration of the overstrain creates a degree of instability, an abnormality of axing so great that the readjustment occurs without nucleus action.

The third case is that in which the watered (moiré) surface of etched tin plate dulls a bright tin plate when pressed against it at 184°, though two bright tin plates thus pressed do not dull each other, and though the watered surface is not affected by contact with dulled tin.

To explain this case it is necessary to suppose that the watered look caused by etching is due to the readjustment and normal axing of the

crystals, so that etched tin and dulled tin are alike in being normally axed.

The fourth case, in which the bright surface of a quietly frozen tin ingot is readily dulled by contact with dulled tin, whereas the surface and even the interior of a tin ingot shaken during freezing has the dulled look of infected tin, and has the power of dulling bright tin, is less easy to explain. It seems necessary to assume that the bright surface of the quietly frozen ingot is in effect overstrained.

The frozen skin of metal may be in unstable equilibrium because it is discordantly axed with regard to the mass underlying it, or its own surface tension may so interfere with the crystallisation of the very skin as to make it unstable.

Overvoltage Phenomena.—The practical significance of overvoltage phenomena is discussed by C. Hambuechen * and their relation to corrosion pointed out. The overvoltage of a certain metal is that excess voltage which is required for the setting free of hydrogen gas at a cathode of the given metal as compared in general with a hydrogen electrode (platinised platinum electrode covered and saturated with hydrogen gas). Under otherwise the same conditions a higher potential is required to set hydrogen free on some metallic plates than on others. Mott gives the following list of overvoltages of hydrogen on various metals : Tin 0·55, lead 0·50, antimony 0·45, bismuth 0·45, gold 0·20, silver 0·15, platinum 0·15, iron 0·10, brass 0·14 volt, copper reference standard. According to the generally accepted theory, the corrosion of metals is caused by galvanic couples due to impurities or electro-negative elements in the metal under consideration, and the rapidity of corrosion will be dependent principally on two factors, the resistance of the local circuits, and the electrochemical voltage. If the latter were the only factor governing the motive force which sets up the current, then simple factors of electrochemical potentials could be used, but the voltage value must be introduced as the active galvanic couples always give rise to the liberation of hydrogen, therefore the overvoltage value should be subtracted from the electrochemical potentials for any couple. As an example, while a list of electrochemical potentials would indicate that tin is as bad as iron for producing corrosion on zinc, the correction for overvoltage—that is, the deduction of 0·55 volts—shows that it is far less harmful.

The " Metallisation " of Surfaces.—Schoop † describes a new process for coating with metals, which can be applied to non-metallic surfaces, and so obviates the inconveniences attaching to galvanic processes or methods of electrolytic deposition. The new process consists in spraying the surfaces to be coated by means of a jet of metal, preferably in a liquid state, at a high temperature. The state of fine subdivision may be obtained

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* Paper read before the Chicago Meeting of the American Electrochemical Society. Abstract in *Metallurgical and Chemical Engineering*, November 1910, vol. viii. pp. 634–635.

† *Revue de Métallurgie*, 1910, vol. vii. p. 585.

by various means which do not in themselves affect the principles of the process. Thus the metal may be projected by centrifugal force or by purely mechanical means, or under the influence of compression. Indeed two jets of metal may be made to impinge with each other at an angle which will determine reciprocal pulverisation and dispersal. When gas or steam under pressure is employed, the process can be carried out as follows. The metal to be used is melted in an appropriate crucible, out of which it flows by gravity or under pressure through a capillary orifice, on leaving which it meets at right angles with the nozzle of a jet of steam or gas in exactly the same way as an ordinary spray diffuser of the old type operates. The gas employed should be as far as possible inert, or, from a chemical point of view, of a reducing nature. An alloy may be used in this process as well as a pure metal, although when an alloy is used the results of pulverisation are not homogeneous, unless the alloy contains its constituents in eutectic proportions. The method thus serves also to yield a simple method of ascertaining the constitution of alloys. The physics of the process appear to involve a flattening of the spherical particles diffused as spray against the object to be coated, and their subsequent cohesion with each other and with the surface. When a pressure of 25 kilogrammes per square centimetre is employed, calculation will show that the metallic particles will move at a rate of over 20 kilometres per second, which is equal to twenty-five times the average speed of travel of a bullet from an ordinary rifle. An interesting fact has been observed in connection with the temperature of the metallic cloud. This is, that its temperature is relatively low, doubtless owing to the cooling influence of the sudden expansion of the jet of gas. This does not, however, affect the process, while it allows of its being extended to cover substances with a low fusion or ignition point, such as paper, wood, and celluloid. The hardness of the surface deposits produced by this process and tested by the Brinell test is distinctly greater than that of metallic coatings produced by other means. Thus, in the case of a deposit of molten tin compared with one of pulverised tin, the hardness number of the latter was 14·2 compared to a hardness number equal to 9·5 in the former instance. This renders the process specially applicable for the manufacture of blocks and electros of all descriptions for printing. When employed simply for decorative purposes a certain degree of porosity in the metallic covering is of negligible importance. On the other hand, it is often required to protect surfaces against chemical or physical influences or the action of the weather. This necessitates the deposit being not only adherent in its nature, but as dense and homogeneous as possible. The deposits produced by the Schoop process will withstand any ordinary mechanical tests, as well as crushing, grinding, and polishing. The surfaces to be treated should be cleansed of all dust or oxide. This can be done by sand-blasting or by pickling. Bars of iron which had been connected by this process and subsequently broken under tensile stress have shown that the surfaces continue to adhere even in the contracted portion, while other test-pieces have undergone ten to twelve bendings, or have been bent to breaking point without the coating having

scaled in any way.   The applications of the process are numerous ; thus aerostatic tissues may by this means be rendered impermeable to water or gas.

V.—*PHYSICAL PROPERTIES.*

Annealing Worked Metal.—As the result of experiments on steel and nickel wires, L. Guillet * concludes that complete annealing, as shown by the attainment of maximum ductility, is reached in three minutes between 750° and 800° for either metal.   Partial softening occurs at 400°, and annealing at low temperature (250° or 300°) appears to raise the breaking load slightly.   Measurements of the elastic limit are less regular, but each metal appears to have two elastic limits, one being the same as for the fully annealed metal, the other variable with the annealing temperature.

Cast Copper of High Electrical Conductivity.—A new method of producing cast copper of high electrical conductivity is given by E. Weintraub,† who points out that the production in the foundry of pure copper castings mechanically sound and possessing an electrical conductivity comparable to that of pure forged copper has been an important problem ever since the development of electrical machinery and apparatus. The cause of the difficulty of producing sound pure copper castings is the presence of dissolved gases, and although the elimination of these gases presents but little difficulty by the addition of deoxidisers such as zinc, magnesium, phosphorus, &c., yet the conductivity of the copper resulting is generally low, because the deoxidisers used have the power of combining with the copper itself.   The author concluded from these considerations that what was needed for the solution of this problem was a deoxidiser which would have no affinity for copper, and during work on the isolation of the pure metal boron, the lack of affinity of this element for copper manifested itself.   Boron has, at the melting-point of copper, a great affinity for oxygen, nitrogen, &c.   Pure boron would probably be too expensive to be used in the production of copper castings, but an amorphous powder containing as impurity only a small quantity of oxygen, and known as boron suboxide, seems very suitable.   This substance is prepared by a modification of the reduction process of boric anhydride by magnesium.   In the first experiment, a sound bar of copper was obtained having a conductivity of 94 per cent. by the addition of only 0·1 per cent. of boron suboxide.

Further experiments proved that the addition of $\frac{1}{30}$ per cent. of boron suboxide was sufficient, and also that the addition of a large excess, say 1 per cent., did not diminish the conductivity or change in any way the mechanical properties of the copper.

* *Comptes Rendus*, 1910, vol. cli. p. 1127.
† Paper read before the Chicago Meeting of the American Electrochemical Society. Abstract in *Metallurgical and Chemical Engineering*, November 1910, vol. viii. pp. 629–630.

A further simplification has been made, in that, instead of producing boron suboxide for addition, the total products of the reduction of boric anhydride by magnesium may be ground up into coarse grains and used. The present foundry practice is to add 1 to 1½ per cent. of this material, which is equivalent to 0·08 – 0·1 per cent. of boron suboxide. The following are the properties of metal obtained by this means :—Electrical conductivity as high as 97·5 per cent. with pure copper ; tensile strength, 24,350 lbs. ; elastic limit, 11,450 lbs. ; elongation, 48·5 per cent. ; reduction of area, 74·49 per cent. The cost of the boron added, at the present prices of magnesium and boric anhydride, is less than 0·75 cent per pound. The success of " boronising " copper suggests new lines of work, which the author is taking up, such as the addition of boron to different copper alloys, and replacing the poling operation during refining by a boronising operation.

Elastic Limit of Metals.—The appearance of slip-bands and crystal boundaries on the polished surface of a metal subjected to stress is employed by O. Faust and G. Tammann * as a means of determining the elastic limit. A cube of the metal is placed between the jaws of the testing-machine, and a polished surface is examined microscopically during the application of pressure. The load at which the first markings appear is taken as the elastic limit. With most metals, the first appearance is that of a few crystal grains being elevated above the general surface, slip-bands only becoming visible later, but copper is exceptional, the slip-bands appearing before the crystal boundaries. The elastic limit is raised by pressure, and a freshly polished surface does not then show markings until the new elastic limit is reached. The highest elastic limit that can be produced by work is the load at which the metal begins to flow freely. This is called the "upper elastic limit." The values found for several annealed metals are as follows (in kilogrammes per square centimetre) :—

Metal.					Elastic Limit. E.	Upper Elastic Limit. F.	$\frac{E}{F}$
Aluminium	.	.	.	.	283	600	2·33
Lead	.	.	.	.	25	102	4·08
Cadmium	.	.	.	.	27·7	109	3·61
Tin	.	.	.	.	34	54·8	1·64
Zinc	.	.	.	.	124	770	6·85
Copper	.	.	.	.	203	2780	13·7
Magnesium	.	.	.	.	118	580	4·92
Nickel	.	.	.	.	788	5570	7·78
Iron	.	.	.	.	2370	5840	2·46

The ratio E F is considered to represent the capacity of the metal for hardening. Chilled castings give a higher elastic limit than slowly cooled castings. The authors explain hardening simply by a reduction in the

* *Zeitschrift für physikalische Chemie*, 1910, vol. lxxv. p. 108.

size of the crystal grain by the formation of gliding-planes. They reject the theory of an amorphous condition in hardened metal, and bring forward various arguments against it.

Electrical Conductivity.—A relation between the specific resistance of copper and its temperature coefficient at any given temperature has been observed by S. Lindesk.[*] At 15° the mean value of the product is 6.78×10^{-5}, and in the case of copper this holds good even when the copper is alloyed with other elements such as arsenic. Aluminium gives the value 11.6×10^{-5}, and iron 58.5×10^{-5}, so that the relation is probably general.

A comparison between the conductivities of a metal at its melting-point, in the solid and liquid states, has been made by E. Wagner,[†] who finds that in many instances a simple relation exists. For mercury, the conductivity of the solid is four times that of the liquid; for lead, tin, zinc, cadmium, thallium, and tellurium it is twice; for the alkali metals, 1.5 times; and for bismuth and gallium, one-half. An explanation, based on the electron theory of conduction, is proposed.

The conductivity of a number of metallic sulphides and ores of low conductivity has been investigated by H. von Martin.[‡] Antimony sulphide behaves exceptionally, the prolonged passage of a current in one direction having the effect of diminishing the resistance, but at the same time increasing the resistance to a current passed in the opposite direction. This polarity disappears slowly when the specimen is allowed to rest for a time without passing a current. It is not due to electrolysis.

Electrical Conductivity of Alloys.—The electrical conductivity of alloys has been studied by Rudolph Schenck.[§] That of an alloy might become smaller than that of the pure metal, either because the foreign metal binds some electrons and diminishes the number of free electrons, or because it increases the internal friction of the solvent. The author favours the latter assumption; the dissolved metal absorbs kinetic energy in its slow diffusion, and that should become discernible in the change of the optical and thermo-electric properties observed on adding another metal to a pure metal. Some of the author's experiments were made with thermo-couples of the type platinum (platinum-rhodium), in which the hot alloy is generally positive to the pure metal, and his observations and formulæ agree with the observations of other investigators.

Heat Capacity of Metals and Compounds.—The heat capacity of fifteen metals and of twenty-nine binary compounds has been determined by H. Schimpff[∥] over temperature intervals of 17° to 100° and 17° to −190°. Within 2 per cent., which is the limit of experi-

[*] *Berichte der deutschen physikalischen Gesellschaft*, 1911, vol. xiii. p. 65.
[†] *Annalen der Physik*, 1910, vol. [iv.] xxxiii. p. 1484.
[‡] *Physikalische Zeitschrift*, 1911, vol. xii. p. 41.
[§] *Annalen der Physik*, vol. xxxii. p. 261.
[∥] *Zeitschrift für Physikalische Chemie*; *Journal of Royal Microscopical Society*, 191 , vol. lxxi. p. 275.

mental error, the molecular heats of about 50 per cent. of the compounds are equal to the sum of the atomic heats of the component metals. In the remaining instances the divergencies from Kopp's law are usually within 4 per cent., except for bismuth and lead. The value of the temperature coefficient diminishes with increasing temperature, while the specific heat increases with the temperature.

Influence of Pressure on the Boiling-points of Metals.— The influence of pressure on the boiling-point of metal has been studied by Harold C. Greenwood.* The experiments were carried out in atmospheres of nitrogen and hydrogen. Expressing pressures in atmospheres or in millimetres of mercury, and boiling-points in degrees centigrade, it was found that bismuth boiled at 1420°, 1740°, 1950°, 2060° under pressures of 1, 6·3, 11·7, 16·5 atmospheres, while at lower pressures of 102 millimetres and 257 millimetres it boiled at 1200° and 1310° C. The figures for lead are :—1320°, 1420°, 1525°, 1870°, 2100° C. under pressures of 105 millimetres, 266 millimetres, and 1, 6·3, 11·7 atmospheres ; silver boiled at 1660° and 1780°, with pressures reduced to 103 and 263 millimetres ; copper at 1980° and 2180°, with pressures at 102 and 257 millimetres. In the case of zinc, the pressure was increased, and the following figures resulted :—Boiling-points, 1120°, 1230°, 1280°, and 1510° C., at 6·3, 11·7, 21·5, and 53 atmospheres. The nature of the gas made no difference at low pressures. Temperatures were determined with the aid of a Wanner pyrometer.

Occlusion of Gases.—The effect of alloying with gold on the occlusion of hydrogen by palladium has been investigated by A. J. Berry,† who finds that the amount of hydrogen occluded diminishes with the proportion of gold in the alloy, reaching zero when the palladium is reduced to 25 per cent.

Plasticity of Tin.—Experiments have been made by E. Jänecke ‡ to determine the plasticity of tin at a number of temperatures between that of the atmosphere and the melting-point. The method used was that of determining the pressure required to produce plastic flow through an opening. The pressure increases regularly with the temperature, no discontinuity corresponding with the transformation of rhombic into tetragonal tin being observed, even after heating for a long time at 200° and cooling slowly. The plasticity of tin depends in a high degree on its previous treatment. Slowly cooled tin flows under a pressure only one-third of that required to cause flow in tin cast in chill. The specific gravity of tin which has been repeatedly compressed is 7·32.

Production of Castings to Withstand High Pressures.— Experiments on various non-ferrous alloys for high-pressure castings

* *Engineering*, September 16, 1911, vol. xci. p. 418.
† *Journal of the Chemical Society*, 1911, vol. xcix. p. 463.
‡ *Metallurgie*, 1911, vol. viii. p. 68.

are described by H. C. H. Carpenter * and C. A. Edwards. The first experiments were carried out on pure gun-metal containing 85 per cent. copper and 15 per cent. tin, a small quantity of copper phosphide being subsequently added to remove oxygen, and in such quantity as not to leave more than 0·1 per cent. phosphorus in the alloy. With this alloy it was possible to produce perfectly sound castings, which, after being machined, withstood a pressure of 18 tons before bursting; in the pressure tests, the castings were filled with water and the pressure pumped up on the top, with oil. In the first experiment on aluminium bronze castings, the alloy contained 91 per cent. copper and 9 per cent. aluminium, and was cast at 1125° C. in chilled moulds.

Out of six castings only one unsuccessful one was obtained, and after machining they were tested up to 12 or 13 tons, when slight stretching resulted and water came through the valve joint; but by tightening up the joints the pressure could be increased to 14 or 15 tons, when further stretching took place; on further tightening up, the pressure was increased to 18 tons, at which none of the castings fractured. Experiments were next conducted on castings made in greensand moulds, and the results showed that the sand-mould castings began to stretch at a lower pressure than chill castings. A series of experiments on the effect of the variation in aluminium content showed that an alloy containing 9·5 per cent. alminium withstood a pressure of 11 tons before bulging, a 10 per cent. alloy withstood 12·5 tons, a 10·5 per cent. alloy withstood 14 tons, and an 11 per cent. aluminium bronze withstood a pressure of 20 tons before any expansion took place. The authors have worked out the conditions necessary for the production of aluminium bronze hydraulic castings capable of withstanding pressures varying from 14 to 20 tons. For large castings the best composition was 9 to 10 per cent. aluminium, and for smaller castings a higher percentage of aluminium could be used. The essential conditions for successful casting are—(1) very slow pouring; (2) casting at a temperature not more than 50° or 80° C. above the initial freezing-point; (3) the metal must enter the mould at the lowest possible point; (4) greensand moulds must not be too damp, and with close sand the lower part of the mould should be dried; (5) with large castings risers must be used to overcome shrinkage.

The homogeneity of the castings seemed perfectly satisfactory, and their corrosion in fresh or in sea water was extremely light. So far as the authors were aware, no other bronzes possessed this combination of properties.

Specific Heats.—A number of specific heats have been determined at low temperatures by F. Pollitzer,† with the object of investigating the influence of this factor on the electrolytic potential. The specific heat of metals, such as zinc and mercury, diminishes rapidly below about − 70°.

* Paper read before the Institution of Mechanical Engineers, December 16, 1910.
† *Zeitschrift für Elektrochemie*, 1911, vol. xvii. p. 5.

The latent heat of fusion of mercury is 554·5 cal. Its specific heat in the liquid state becomes abnormally large in the neighbourhood of the freezing-point, that of solid mercury being normal.

Stresses in Cold-worked Metals.—An important series of experiments to determine the internal stresses in cold-worked metals has been carried out by E. Heyn [*] and O. Bauer. As a cold-rolled rod, for instance, has the outer layers in a state of tension, and the inner core in a state of compression, when a thin layer is removed from a test-piece by turning, the stress is partially removed, and the test-piece increases in length. The stress originally existing in the nth layer thus removed by turning is

$$\sigma_n = \frac{E}{l} \cdot \frac{f''_n (l_n - 1) - f''_{n-1} (l_{n-1} - 1)}{f'_n},$$

where E is the modulus of elasticity, f'' is the section after removal of the layer n, f' the cross-section of the layer removed, and l is the length between datum marks. A check on the measurements is afforded by the condition that the sum of the tensile stresses thus found must equal the sum of the compressive stresses. In the actual experiments, fifteen such layers were usually removed in succession. Metal in the annealed condition, tested in this way, proved to be practically free from internal stress.

As these stresses balance one another, they should be without influence on the specific gravity of the metal. Actual experiments with cold-rolled aluminium bronze showed that the specific gravity steadily diminished as layers were removed by turning. The annealed metal had a uniform specific gravity throughout. The diminished specific gravity observed in most cold-worked metals is attributed to elastic deformation, the return of the metal being hindered by friction. The results are used to explain certain cases of cracking after cold-working, such as the cracking of turbine blades in consequence of unequal heating, of cartridge-cases through painting at the neck with vermilion paint, and of aluminium vessels through corrosion. The authors point out the danger of specifying very high elastic limits and breaking loads in the case of non-ferrous metals on account of the danger of producing internal stresses through excessive cold-working.

The Alkali Metals.—New determinations of the coefficient of expansion of the alkali metals have been made by L. Hackspill,[†] the metals being distilled *in vacuo* into a glass dilatometer, filled with an inert liquid. The following results are obtained :—

[*] *Internat. Zeitschrift für Metallographie*, 1911, vol. i. p. 16.
[†] *Comptes Rendus*, 1911, vol. clii. p. 259.

	Sodium.	Potassium.	Rubidium.	Caesium.
Density at 0°	0·9725	0·859	1·525	1·903
Coefficient of expansion—solid	0·000216	0·00025	0·00027	0·00029
,, ,, liquid	0·000275	0·000280	0·000339	0·00034
Expansion on melting . .	Per Cent. 1·50	Per Cent. 2·42	Per Cent. 2·28	Per Cent. 2·32

The Hall Effect in Alloys.—Determinations of the Hall magnetic effect, the Nernst effect, the electrical conductivity and its temperature coefficient, and the thermo-electric power have been made by A. W. Smith,[*] in the case of alloys of antimony with bismuth, cadmium, and zinc respectively. Alloys of antimony and bismuth, which consist of a continuous series of solid solutions, give continuous curves in every case, but the existence of the compounds SbCd and SbZn is indicated by the presence of well-marked singularities in all the curves. The change of resistance of the bismuth-antimony alloys when brought into a magnetic field has been studied, and it has been found that this change is not an additive property of the alloys.

Viscous Flow in Metals.—E. N. da E. Andrade[†] has investigated the law of the variation of viscous flow in wire loaded beyond the elastic limit. The bulk of the experiments were carried out on lead wires, and the following conclusions were arrived at :—

(1) Viscous flow exists in lead, lead-tin alloy, and in copper.

(2) To reduce variation it is necessary to work at constant stress, and to use the "hyperbolic weight" for this purpose.

(3) At constant stress the flow is purely viscous right up to breaking for the metals used.

(4) The empirical formula

$$l = l_0 (1 + \beta t^{\frac{1}{3}})e$$

is shown to fit very closely all the extension curves, and the flow can be divided into β flow and viscous flow.

(5) The β flow is experimentally shown to tend to a limit for large stresses.

(6) The β flow is shown to tend to the same limit at 162° as at 15°.

(7) The curve of fluidity against stress is shown roughly to be a hyperbola with one asymptote parallel to, and the other steeply inclined to, the stress axis.

* *Physical Review*, 1911, vol. xxxii. p. 178.
† *Proceedings of the Royal Society*, 1911, Series A, vol. lxxxiv. p. 1.

ANALYSIS, TESTING, AND TEMPERATURE MEASUREMENT.

CONTENTS.

I.—*ANALYSIS.*

Aluminium Ores.—An approximate valuation of an aluminium ore may be made, according to J. Calafat y Leon,* by mixing the roughly crushed ore with an equal volume of dry sodium carbonate and heating on charcoal in an oxidising flame. After dissolving in water and filtering, carbon dioxide is passed through the solution, and the precipitate of alumina obtained is compared with that given by an equal quantity of bauxite under the same conditions. Clay, kaolin, and other aluminium silicates do not yield alumina in this test, and it therefore represents the availability of the ore as a source of aluminium.

Analysis of Aluminium Alloys.—An article on the analysis of aluminium and aluminium alloys is given by T. Smith,† in which it is stated that at the present time there is no method for the direct estimation of aluminium in alloys high in this element, and that the amount present as obtained by difference is the best that can be done. Details are given for the estimation of silicon and iron in aluminium and of copper in alloys by electrolytic or cyanide methods, for zinc in alloys by precipitation as sulphide in a formic acid solution followed by solution and precipitation as phosphate.

The author concludes that the chief causes of poor results in these analyses are :—The impossibility of securing even an approximate result by estimating aluminium in the usual manner, and this is increased by the use of glassware in precipitating. The attempt to estimate iron on too small a weight of material, and the attempt to precipitate and filter zinc from an alkaline solution in place of the newer and better method using formic acid.

Anomalous Behaviour of Delicate Balances.—J. J. Manley * gives an account of experimental work carried out with the object of ascertaining the causes of the variations in the resting - point of a balance. The causes are ascribed as being due to :—(1) Side-slipping of the central knife-edge upon its supporting plane ; (2) differential and continued flexure of the beam after loading ; (3) lateral displacement of one or more knife-edges ; and (4) small variations in the temperature of the two arms of the beam. Each of the above conditions is investigated in detail, both experimentally and theoretically, with the result that the anomalous behaviour of a balance is shown to be due almost entirely to causes 3 and 4, and that 1 and 2 are for all practical purposes inoperative. A distinct advantage is gained by surrounding the beam with an extra inner case consisting of metal, wood, and plate-glass, so as permanently to screen it from heat radiations and convection currents. The efficiency of various forms of knife-edges employed in balances is also discussed.

Assay Gold.—The spongy gold obtained after parting assay beads rich in silver is described by M. Hanriot,† under the name of brown gold. It contains nitric acid, and shrinks greatly on heating, liberating gas at 900°. If the alloy has not been annealed before parting, a much larger quantity of silver remains in the gold. The amount of shrinkage during parting, measured by means of lines ruled on the cornets before parting, depends on the composition of the bead taken, but is independent of the thickness of the cornet, and of the parting temperature.

Chemical Analysis of Spelter.—A detailed description of the methods employed for the estimation of zinc and the common impurities in spelter is given by A. M. Fairlie.‡

The precautions necessary to secure a true average sample are discussed.

A standard solution of potassium ferrocyanide is prepared by dissolving 21·63 grammes of pure potassium ferrocyanide with 7 grammes of sodium sulphite in 1 litre of distilled water ; 1 c.c. of this standard solution should be equivalent to 0·005 grammes of zinc ; 4·4 grammes of uranium acetate in 100 cubic centimetres of distilled water is recommended as the indicator.

Special precautions to be observed in standardising are dwelt upon at some length.

Solution is effected in nitric acid ; lead is precipitated as lead sulphate, copper cadmium, and bismuth, if present on metallic aluminium. The filtrate is neutralised with dilute caustic soda, and rendered barely acid by addition of 50 per cent. formic acid. After diluting to 200 c.c. and heating to 80° C., the zinc is precipitated as sulphide, by a special method first published by W. G. Waring. § Hydrogen sulphide is

* *Proceedings of the Royal Society*, 1911, Series A, vol. lxxxiv. p. 389.
† *Comptes Rendus*, 1910. 1911, vols. cli. p. 1355, and clii. p. 138.
‡ *Metal Industry*, October 1910, vol. ii. p. 350.
§ *Journal of the American Chemical Society*, 1904, vol. xxvi. pp. 4–29.

passed through a tube fitted with a rubber cork inserted loosely into the flask containing the hot zinc solution, the stopper being pushed in tightly when precipitation of the zinc sulphide is well under way. It is stated that the precipitate settles quickly, is pure white, pulverulent, and very easily filtered and washed. It is dissolved in strong hydrochloric acid made up to 200 c.c., with hot water heated to 60°, and titrated with ferrocyanide after adding a little ammonium chloride.

(Reference may also be made to " The Technical Assay of Zinc ").*

Determination of Cadmium in Spelter.—Three methods for the determination of cadmium in spelter are given by A. M. Fairlie.†

The spelter should be slowly dissolved in dilute hydrochloric acid, the procedure being so arranged that out of 20 grammes taken about 1 gramme is left undissolved. It is stated that this undissolved zinc will have all the cadmium and some lead precipitated upon it: it is transferred to a small filter, washed with hot water, and dissolved in 5 to 10 c.c. of dilute nitric acid, the lead being then precipitated as sulphate in the usual manner. The filtrate is carefully neutralised with ammonia, diluted to about 500 c.c., made faintly acid by addition of 8 drops of hydrochloric acid, heated to 75° C., and saturated with hydrogen sulphide. Should no precipitate appear, a few drops of ammonia are added, with constant stirring, until a decided precipitate of zinc sulphide appears. This is filtered, washed with hot water, and dissolved on the filter with hot dilute (1 : 1) hydrochloric acid : this process is repeated until a filtrate is obtained which shows no zinc on addition of excess of ammonia. The final precipitate is weighed as cadmium sulphide.

Another method described proposes the precipitation of cadmium with metallic aluminium, in a strongly acid and boiling solution, and weighing as metal.

A third method provides for the vigorous stirring, in dilute hydrochloric or sulphuric acid, of the zinc and cadmium sulphides ; the zinc sulphide goes into solution, while the hydrogen sulphide evolved prevents solution of the cadmium sulphide, which is warmed with acid ferric sulphate, and titrated with permanganate.

Determination of Lead.—Various published methods for the determination of lead in non-ferrous alloys are reviewed by C. P. Karr, ‡ and their respective merits and demerits discussed. The author proceeds to describe two new methods, one planimetric, the other electrolytic. The former depends on the elimination by the usual means of all metals except lead and one other. These are obtained in a sulphate solution, and evaporated to dryness. The product is then ignited and reduced to a prill in a porcelain crucible. After cooling it is flattened, and etched with nitric or sulphocyanic acid. An enlarged photomicrograph is prepared to scale for comparison with a range of standard micrographs of known compositions. The ratio which the proportional area of the

known composition bears to the percentage of the ingredient known, is the same as that which the proportional area of the required ingredient (as measured by the planimeter) bears to its required percentage composition.

In the electrolytic method the lead is deposited from a strong nitric acid solution as lead dioxide on a revolving anode. When deposition is complete, the anode is dipped in hot water and then in alcohol, after which it is dried for an hour at 230° and weighed. This weight has to be multiplied by an empirical factor, variously estimated at 0·8643, 0·857, and 0·866, owing to differences in the thoroughness of the expulsion of water from the deposit. To avoid this difficulty, it is suggested that a platinum dish be used as anode, and the deposit converted into lead oxide by ignition.

Dissolving Tin Ores.—Refractory tin ores are readily brought into solution, according to A. Gilbert, * by fusing with sodium hydroxide in a silver crucible, adding a very small quantity of finely powdered wood charcoal. A vigorous reaction takes place, and after dissolving in water, the whole of the tin is found in solution, iron oxide remaining insoluble. Copper and sulphur should be removed previously by roasting and extracting with acid. The charcoal used is only a small fraction of that required to reduce the tin oxide.

Electrolytic Separations.—M. E. Holmes† and M. V. Dover say that cadmium is conveniently deposited from organic electrolytes (formate, acetate, or lactate) with a low current density and rotating anode.

In the analysis of copper pyrites, W. C. Blasdale ‡ and W. Cruess state that the copper may be deposited completely in ninety minutes with the Winkler electrode in sulphuric acid solution, if arsenic is absent. If arsenic is present, nitric acid and carbamide should be added, or the copper may be deposited as usual, re-dissolved in nitric acid, and again deposited.

A number of methods for the quantitative electrolytic separation of pairs of metals are also described by I. H. Buckminster § and E. F. Smith.

Estimation of Antimony and Tin.—An article by W. B. Vietz ‖ describes a modification of the Low method for the estimation of antimony and tin in solders, &c. The sample is dissolved in strong sulphuric acid and copper estimated colorimetrically; the solution is diluted, and 10 c.c. of hydrochloric acid added, when the antimony may be determined by titration with a standard solution of potassium permanganate, prepared by dissolving 3·21 grammes of the salt in a litre. One gramme of powdered antimony and 25 to 50 c.c. of hydrochloric acid are then added, and the stannic chloride reduced by boiling for two or three

* *Zeitschrift für öffentliche Chemie*, 1910, vol. xvi. p. 441.
† *Journal of the American Chemical Society*, 1910, vol. xxxii. p. 1251.
‡ *Ibid.*, p. 1264.   § *Ibid.*, p. 1471.
‖ *Metal Industry*, August 1910, vol. ii. p. 269.

minutes under a stream of carbon dioxide ; after cooling, the solution is titrated with a standard solution of iodine, containing 13 grammes to the litre, using starch solution as indicator.

(A correspondent, writing in a later issue, recommends the addition of the following mixture, which is stated to render the end point of the permanganate titration more readily distinguishable, viz. 45 grammes manganese sulphate, 93 c.c. of phosphoric acid (85 per cent.), 279 c.c. sulphuric acid, made up to 1 litre of distilled water.)

Estimation of Titanium.—Titanium may be separated quantitatively from many metals by a method described by K. Bornemann [*] and H. Schirmeister. Titanium is precipitated completely by ammonia, and can thus be separated from copper and nickel. When iron is present, the acid solution is reduced with sulphurous acid, and warmed with ammonia and potassium cyanide. The precipitated titanic acid is free from iron, and the iron in the solution of ferrocyanide may be estimated in the usual way.

The alloy is best brought into solution by fusion with potassium hydroxide and sodium nitrate.

Ferro-Uranium and Ferro-Zirconium.—Methods for estimating uranium and zirconium in their alloys with iron, in which form they now come into commerce, are described by W. Trautmann.[†] The uranium alloy is dissolved in *aqua regia*, diluted, precipitated with solid ammonium carbonate, and the filtrate, containing the whole of the uranium, is boiled, a few drops of ammonia being then added. The precipitate of uranium is pure, and is weighed as U_3O_8. The zirconium alloy is roasted in a platinum crucible, fused with sodium carbonate and nitrate, dissolved and evaporated with hydrochloric acid to remove silica, and the zirconium is then precipitated by boiling with sodium thiosulphate.

Labour - saving Appliances in the Laboratory.—Various mechanical devices are described and illustrated by E. Keller,[‡] by means of which multi-manipulations in the laboratory can be condensed into single manipulations. For example, details are given of the means of depositing in or withdrawing from the muffle forty-eight cupels as one unit. A parting-bath with sectional holders for test tubes is also described, having a wooden handle at each end. A device is also shown by means of which each set of tubes is filled with water at one operation, and an annealing cup holder which enables the operator to transfer the gold from the tube to the cups in sets.

Matte Assay of Cupriferous Gold-bearing Materials.—L. J. Wilmoth [§] publishes further results of the matte assay as previously

[*] *Metallurgie*, 1910, vol. vii. pp. 711, 723.
[†] *Zeitschrift für angewandte Chemie*, 1911, vol. xxiv. p. 61.
[‡] *Bulletin of the American Institute of Mining Engineers*, August 1910, No. 44, pp. 633–636.
[§] *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, December 1910, vol. xi. pp. 240–242.

applied to the assays of battery chips and screens.* In the assay of auriferous copper drillings the method is found to give equally good results as the scorification and combination methods generally used. The following charge was used for metallic copper :—

Drillings, 10·0 grammes ; litharge, 1·0 assay ton ; sodium carbonate, 1·5 assay ton ; borax, 1·0 assay ton ; silica, 0·5 assay ton ; charcoal, 1·25 gramme ; sulphur, 8·0 grammes ; and a stout iron nail.

The lead button is separated and cupelled, and the matte and slag scorified separately, and the lead cupelled. Results obtained by the application of the same method to rich copper-bearing materials, &c., are given.

Rapid Electrolytic Determination of Lead and Copper.—A new form of gauze cathode for the rapid electrolytic determination of lead and copper is described by R. C. Benner.† In the case of lead, when the peroxide is deposited on the inside of a platinum dish, it is possible to ignite the peroxide, changing it to litharge, in which form it may be weighed without error ; but when the deposition is made on a gauze electrode, it is impossible to ignite over the Bunsen burner, as some of the litharge is volatilised, or some of the peroxide remains undecomposed, giving low or high results respectively. This may be obviated by igniting the gauze electrode in the muffle below 500° C. The electrode designed by the author consists of sand-blasted gauze, and the methods of connection recommended are shown in diagrams.

Methods are given for the analysis of lead ores, copper ores, copper slags, and copper ores containing large amounts of iron.

The following are considered to be the chief points to be observed in the electrolytic determination of lead and copper :—

1. The cathode must be completely covered by the electrolyte.

2. Electrolysis must not be stopped until precipitation is complete. The time of deposition varies with different electrodes, volume of solution, amount of metal, &c., even if current is same in each case. These facts are especially true with rapid methods, and with the gauze electrode in particular.

3. Dissolve and re-deposit all dark-coloured copper precipitates, as they frequently give high results. This may be due to the oxidation of the copper, or to the presence of interfering elements.

4. Adjust electrodes so that current density is as nearly the same as possible at all points.

5. In selecting gauze electrodes, choose those which will allow the best circulation, and as large a surface as is convenient.

6. Under some conditions the deposited copper is likely to be spongy, but will give good results if the deposit is not washed off.

7. Do not try to deposit more than 0·2 to 0·3 gramme of copper or lead, as such deposits are not as good as when small amounts are used.

8. Do not allow the electrolyte to boil away, as the concentration of the acid is likely to cause the solution of the copper.

Sampling Anode Copper.—The sampling of anode copper is dealt with by W. Wraith,* who gives an account of a dispute between a smelter and a refinery as to silver contents, and an investigation of the sampling methods of each. At the smelter a "shotting" method was employed by pouring 4 to 6 ounce samples at hour intervals of the molten metal as it flows from the furnace, while the anode method, by which every fourth anode is drilled by using, in order, the holes of a standard template, was the method used at the refinery. A "ladle-shot" sampling was also investigated, and the analytical results of all three are compared. The conclusions reached were that the shot samples taken from the furnace stream, and the drillings from every fourth anode, by the template method, will check within practical limits, and give a true silver content of the copper; but that the ladle-shot method will give a high silver contents owing to a segregation of silver toward the portion that solidifies first.

Standardisation: Bullion and Assay Values.—The following definitions † have been adopted by the Institution of Mining and Metallurgy :—

(1) Assay reports shall state the exact condition of the sample as to dryness when assayed.

(2) Assay values of gold and silver ore and products shall be represented in pennyweights and decimals or in ounces and decimals, and not in ounces, pennyweights, and grains. They shall be expressed in terms of fine gold and fine silver respectively, not as " bullion."

(3) Assay values of alluvials shall be reported in grains and decimals of a grain of " fine " gold, or in pence (at 2d. per grain of " fine " gold), or cents per cubic yard.

It is recommended that, in the absence of specific information as to boulders, &c., one cubic yard of ordinary alluvial be taken as equivalent to 3000 lb. (1½ short tons).

(4) In reporting assay values of cyanide and other solutions, the results shall be given in parts by weight in a stated volume of the solution.

In the case of cyanide solutions, the use of the " fluid ton of 32 cubic feet " is recommended. It closely approximates to 2000 lb., and is in common use.

(5) When it is necessary to state or estimate the money value of an ore, &c. (other than of gold), it shall be accompanied by the assay value, and the basis on which the former has been calculated from the latter shall be stated.

(6) Laboratory sieving tests shall be made with the I.M.M. Standard sieves, or, when other sieves are used, the width of the apertures shall be stated.

Note.—Reports of assay results, extraction tests, metallurgical and ore-dressing trials, &c., are sometimes so worded as to permit a wrong

* *Bulletin of the American Institute of Mining Engineers*, 1910, p. 209.
† *Bulletin of the Institution of Mining and Metallurgy*, January 1911, No. 76, p. 31.

interpretation, and the Council urge the necessity for definite statements as to the nature and condition of the sample assayed, and, where advisable, an indication of the method of assay. Thus, in the case of such metals as copper, tin, lead, antimony, &c., where both " wet " and " dry " methods of assay are in use, results should be reported as obtained by " fire " assay or by " wet " assay, with further details as to method, if judged advisable. Similarly, it should be stated whether the sample was assayed in the condition in which it was received, or " air-dried " or dried at – ° C.

In reporting that an assay for such a constituent as tin, arsenic, tungstic acid, &c., corresponds to so much " black tin," " white arsenic," " wolfram," or other recognised saleable product, the report should give the assay result for such constituent, together with a definite statement as to the figures used in calculating such saleable product. Thus, an assay showing 1 per cent. of metallic tin might be reported as 1 per cent. of metallic tin, equivalent, if all could be extracted as such, to 1·5 per cent. of " black tin " containing 66·6 per cent. (or two-thirds) of its weight of metallic tin. Similarly, in reporting results, where assay values might be mistaken as representing available produce, it should be stated that such are merely " gross " assay values, a statement or estimate of the actual " commercial " values being added whenever possible.

In such matters as ore-dressing, ore-treating processes, furnace work, &c., where so much depends on the way in which results are reported, on the nature of the sample and on the method of taking it and its relation to other samples, the Council emphasise the necessity for careful phraseology and for the inclusion of exact data, as also the necessity for care in preparing, describing, labelling, sealing, and otherwise insuring the correctness and authenticity of samples substituted for tests or assays.

Tellurium.—The reduction of tellurium by hydrazine is usually incomplete. It is shown by A. Rosenheim * and M. Weinheber that the reduction is incomplete when the solution is heated to 130° in an autoclave. Telluric acid is too weak to be titrated directly, but it forms a complex acid with glycerol, which may be titrated satisfactorily, using phenolphthalein as an indicator. A still better method is to add to the solution of telluric acid an excess of $N/10$ barium hydroxide, filter off the barium tellurate, and titrate the filtrate with $N/10$ oxalic acid, using phenolphthalein. The results are sufficiently accurate.

Tungsten.—B. Mdivani † recommends adding to the solution of an alkaline tungstate a freshly prepared solution of stannous chloride in hydrochloric acid, boiling, collecting the blue precipitate, and weighing after ignition to trioxide.

Volumetric Estimation of Nickel and Cobalt.—H. Grossmann ‡ describes a method for the volumetric estimation of nickel and

* *Zeitschrift für anorganische Chemie*, 1911, vol. lxix. p. 266.
† *Bulletin de la Société Chimique*, 1911, vol. [iv.] ix. p. 122.
‡ *Revue de Métallurgie*, 1910, vol. vii. p. 1124.

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cobalt, based on the behaviour of pure salts of these metals in cyanide of potassium, in such circumstances as when the quantity of cobalt present is not more than 7 to 8 per cent. of that of nickel. This proportion is that which usually obtains in commercial products, such as nickel steels and rolled nickel. The method depends on the specific manner in which cobalt behaves as regards potassium cyanide in the presence of larger quantities of nickel, and, on the other hand, by a judicious combination of the Moore process for the titration of nickel with the dicyandiamidine process previously described by the author.

White Metals.—F. Kietreiber * recommends heating the alloy with nitric acid, and evaporating down with sodium sulphide, fusing the mass, and digesting with hot water, when tin and antimony are dissolved and lead and copper remain insoluble.

E. Schürmann † recommends the conversion of the alloy into a mixture of bromides by treatment with a solution of bromine in chloroform or carbon tetrachloride, and shaking the product with a solution of oxalic acid in water, which dissolves antimony.

II.—*METALLOGRAPHY.*

A Modified Microscope.—A modification of Stead's workshop microscope is described by S. Prauss.‡ In order to render the instrument available for the examination of surfaces at any inclination to the horizontal a jointed arm is provided, by means of which the microscope may be held in any position, the arm being attached to the mass of metal to be examined by means of a hand-vice, or in the examination of masses of steel, &c., by a portable electro-magnet. The polishing, etching, and examination of any desired surface occupies only a few minutes.

A new form of camera for metallographic work is described by Heimstädt.§ The instrument is constructed on the principle of the reflex hand camera, the ground glass screen being at the side, with a mirror at an angle of 45°. After focussing is complete, the mirror is turned to expose the plate, the shutter having been previously drawn. Vibration when using high powers is thus reduced to a minimum.

Magnetic Specimen-Holder for Microscope. — A magnetic specimen-holder for metallic specimens, used under a high-power instrument, has been patented by A. Sauveur,‖ and is described and illustrated. By the use of a V-shaped opening and scales, the portion of any specimen under the microscope may be readily replaced, and this

* *Oesterreichische Chemiker-Zeitung*, 1910, vol. [ii.] xiii. p. 185.
† *Chemiker Zeitung*, 1910, vol. xxxiv. p. 1117.
‡ *Metallurgie*, 1911, vol. viii. p. 124. § *Ibid.*, p. 137.
‖ *Metallurgical and Chemical Engineering*, February 1911, vol. ix. p. 95.

is very convenient, for it is often necessary to re-examine a specimen at exactly the point first observed.

Solid Solutions.—In an article on "The Aims of Metallography," W. Guertler * points out the technical importance of the study of solid solutions, of thermal equilibrium, and of the relation of physical and mechanical properties to chemical constitution and crystalline form.

III.—*TESTING*.

Impact Testing Machine.—A new impact testing machine is described by D. R. MacLachlan.† The machine, which is illustrated by several photographs and diagrams, is designed to secure that by direct application of the blow as little as possible of the energy of the falling weight is absorbed by the connections. The energy absorbed in fracturing the specimen is measured in two ways—by the alteration of the velocity of the falling weight during the fracture of the test-piece, and also by the difference between the initial potential energy and the residual kinetic energy in the weight after fracture.

Vertical Magnifier.—A little instrument, devised as a convenient and inexpensive means of measuring the impressions in metal specimens made by Brinell ball tests, is described by H. M. Boylston.‡

It consists of a double lens made up of two plano-convex lenses, having a combined focus of 38 millimetres, and adjusted in a cylindrical mount about 3 inches high and open at the bottom. Provision is made for vertical illumination, and a small scale is added for measuring small distances accurately. A brilliant illumination is obtained by inserting a plain glass reflector in a slot cut in the cylindrical mount at an angle of 45°, one side of the cylinder being left open to admit light from any convenient source.

In using the instrument, it is held in one hand with the opening directed to the source of light, while the specimen, with impression uppermost, is held against the steel scale with the other hand in such a position that the scale corresponds with a diameter of the circular edge of the impression, one of the graduations of the scale being set tangent to an edge of the impression. The diameter of the impression can thus easily be read.

IV.—*TEMPERATURE MEASUREMENT*.

Autogenous Welding of Thermo - Couples. — The ordinary method adopted for the fusion of couple wires used at high temperatures

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* *Internat. Zeitschrift für Metallographie*, 1911, vol. i. p. 1.
† *Engineering*, December 23, 1910, vol. xc. p. 860.
‡ *Metallurgical and Chemical Engineering*, January 1911, vol. ix.

necessitates the use of compressed oxygen, or if the alternative method of soldering with palladium be used, compressed air is essential.

P. B. Crossley * points out that the above methods are not always convenient, and describes the following method by the use of the electric arc. The couple is clamped in a stand, and the ends are twisted for a length of about 5 millimetres. Contact of the free ends of the couple is made to one terminal of an electrical circuit containing a switch, while to the other terminal is connected a short length (30 centimetres) of platinum wire, subsequently used to form the arc. To effect the fusion the switch is closed and the platinum wire is brought into contact with the twisted ends of the wires of the thermo-couple, then instantly removed to a sufficient distance to strike the arc and then immediately withdrawn.

The strength of the current used is 1·8 amperes at 440 volts. By the use of borax as flux, platinum and copper leads may be fused by electric arc.

Compensating Gas-filled Recording Thermometer.—A new form of gas-filled Bristol recording thermometer is described † for recording lower ranges of temperature. These thermometers are equipped with a patented compensating device which automatically corrects for changes of temperature at the recording instrument. They are equipped with sensitive bulb and flexible connecting tube. The sensitive bulb is generally about 10 inches long and ¾ inch in diameter, and the quantity of gas contained in the bulb is very large in proportion to the volume of gas contained in the capillary tube between the bulb and the recording instrument, this making the error due to changes of temperature along the connecting tube negligible. Illustrations are given showing the construction of the recording instrument and records of feed-water temperatures and condenser-water temperatures.

Radiation Pyrometer.—A new type of radiation pyrometer, embracing several novel features, has recently been devised by R. P. Brown,‡ of Philadelphia. In radiation pyrometers of the fixed focus type, the pyrometer should not be more than 30 inches from the furnace opening when this is 3 inches in diameter, or 60 inches distant when the opening is 6 inches in diameter.

To avoid the necessity of measuring the distance, the Brown pyrometer is fitted with a finder, so that the proper distance from the furnace is indicated when the bright opening of the furnace takes up the whole view of the finder. Another feature of the Brown pyrometer is the collapsible tube which permits of the pyrometer, indicator, tripod, and wiring being fitted into a small leather case weighing only 15 lbs.

* *Metallurgical and Chemical Engineering*, November 1910, vol. viii. p. 612.

† *Ibid.*, January 1911, vol ix. pp. 56–57.

‡ *Ibid.*, December 1910, vol. viii. p. 703.

FURNACES AND FOUNDRY METHODS.

Automatic Annealing Furnace. — An illustrated description is given of a new automatic annealing furnace invented by C. Bleyer.* All the operations are performed by electric motors, and the furnace is heated by means of two oil fuel burners similar to those used for melting metals.

The oblong shell of the furnace is formed of six heavy cast iron plates bolted together; it is lined with 4 to 8 inches of firebrick, an interlining of asbestos being interposed for heat insulation. The furnace is charged from an overhead hopper; the flames enter the bottom of the furnace, but are deflected outwards so as not to make contact with the castings. This furnace is particularly suitable for light castings such as cartridge shells, and for any kind of small grey iron or metal castings requiring a short annealing period.

Briquetting Turnings and Borings. — Metal turnings and borings from machine shops are now briquetted by the Ronay system without the use of any binding material, as described by E. Schumacher.† The turnings, &c., are cleaned and are subjected to a pressure of 1600 to 2000 atmospheres, the air being removed during compression. The briquettes are compact, and retain their shape when heated until the melting-point is reached.

A new machine for briquetting metal borings, &c.,‡ without the aid of a binding material is described and illustrated. The material is compressed at pressures of 12,000 to 30,000 lbs. per square inch. The most important feature of the process is said to be the provision for the escape of all air from the briquette during its formation : it is pointed out that were such intermingled air merely compressed with the material, it would simply re-expand upon the release of the pressure, and the briquette fall to pieces. The first cost of the necessary equipment is said to be high, but the subsequent cost of treatment is put at from 1s. to 1s. 3d. per ton.

Casting Bronze Propellers. — The methods of moulding and casting marine propellers are described by H. Vetter,§ the chief attention being given to the construction of the mould and to the manner of cast-

* *Metallurgical and Chemical Engineering*, November 1910, vol. viii. pp. 648-649.
† *Giesserei-Zeitung*, 1910, vol. vii. p. 553.
‡ *Brass World*, February 1911, vol. vii. p. 43.
§ *Giesserei-Zeitung*, 1910, vol. vii. pp. 626, 663.

ing in order to secure homogeneity. Large bronze blades should be cast vertically with the flange upwards, although a certain porosity of the flange is unavoidable. Blades have been cast with the flange downwards, giving a very smooth external surface, but internal porosity is then to be feared.

Furnaces for Melting Brass and Other Alloys. — An article by J. Horner * is devoted to the consideration of the various types of furnaces employed for melting brass and other alloys. Several pages are devoted to illustrations and detailed drawings of various types. In addition to the standard patterns using coke as fuel, others are described and illustrated as being especially adapted for burning town and producer gas, and cheap petroleum residues. Most of the newer types are of the tilting pattern, by the adoption of which it is claimed the wear and tear on crucibles is reduced to a minimum.

Japanese Bronze Casting.—Japanese methods of casting ornamental bronze objects are described by H. Heiland. † The most characteristic features are the use of wax models, and the practice of casting even small objects in a number of parts which are subsequently soldered together. The moulds are heated, often very strongly.

Remelting of Aluminium Chips or Borings.—The precautions necessary to be observed in remelting aluminium chips or borings ‡ are detailed. Iron must be removed, or the resulting metal will have a coarse grain and be quite brittle : this removal is easily effected by a magnet machine. No satisfactory method for removing brass or babbitt metal chips has yet been devised, although it is suggested that a concentration method might be employed. A small quantity of the latter is said not to affect the aluminium for ordinary work. To prevent excessive oxidation the chips should be added in small quantities at a time to already molten metal with *immediate* stirring. After skimming, a few pieces of chloride of zinc are thrown on the surface and the metal stirred. Graphite stirrers should be used in preference to iron.

* *Engineering*, October 21, 1910, p. 559.
† *Giesserei-Zeitung*, 1910, vol. vii. pp. 593, 622.
‡ *Brass World*, August 1910, vol. vi. p. 278.

STATISTICS.

Gold in the Transvaal.—According to H. F. Mariott,[*] the gold production in the Transvaal during 1910 may be estimated to have been of the value of £32,075,000, as compared with £30,925,788 in 1909. About 24,794 white men and 201,770 coloured labourers were employed in this production, which involved, in the Witwatersrand district alone, the milling of 21,500,000 tons of ore, averaging £1, 8s. 6d. per ton.

Metallurgy in Colorado during 1909.—The decrease in the production of ore suitable for smelting in Colorado is shown by the following figures compiled by F. Guiterman. [†]

	1900.	1909.	Decline, Per Cent.
Gold, oz.	1,400,000	1,061,000	24·21
Silver, oz.	20,300,000	8,900,000	56·16
Lead, lbs.	82,137,000	32,360,000	60·60
Copper	No change.	No change.	No change.
Zinc	,,	,,	,,
Value	$50,314,000	$30,196,000	38·55

Platinum in Russia.—The production of platinum in Russia [‡] in 1909 was 275,000 ounces, which includes the metals surreptitiously exported to evade payment of the Government tax. The estimated output for 1910 is 300,000 ounces of crude metal, containing about 83 per cent. of platinum.

Portuguese Metal Production.—The following figures have been issued by the Association of Portuguese Civil Engineers [§] relative to the statistics of the mineral production of Portugal during 1909 :—

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[*] *Engineering and Mining Journal*, January 7, 1911, vol. xci. p. 80.
[†] *Metallurgical and Chemical Engineering*, January 1911, vol. ix. p. 19.
[‡] *Engineering and Mining Journal*, vol. xci. p. 130.
[§] *Revista Minera*, vol. lxi. p. 454 ; *Revista de Obras Publicas e Minas*, Lisbon.

	Tons.
Antimony	6,246
Arsenic	1,422,259
Carbon	8,978,457
Lead	705,828
Argentiferous lead . . .	29,916
Copper	211,799,268
Tin	16,000
Gold	0·025,396
Auriferous silver . . .	2,325
Wolfram	673,079

Production of Copper in the States.—Attention is drawn to the tremendous magnitude of Western copper operations.* The Utah Copper Company is at present the largest producers of copper concentrates; the original plant had a daily capacity of 6000 tons of ore, averaging 2 per cent. copper; improvements have raised this to 10,000 tons, which is the official figure given in the company's last quarterly report. The Boston Consolidated Mill, which has been acquired by the Utah Copper Company, had an original capacity of 3000 tons per day, but this has now been raised to 6000 tons.

The Nevada Consolidated Copper Company is at present treating 5000 tons of 2 per cent. ore daily; if plans are carried out, it will eventually treat 15,000 tons daily. This mill is constructed in units of 1500 tons capacity each. The Ray Consolidated Copper Company, Arizona, is not yet producing, but gives promise of being a large factor. The assured ore in Ray properties is 59,000,000 tons, and the acquisition of the stock of the Gila Copper Company adds 16,000,000 tons, or a total of 75,000,000 tons of 2 per cent. ore. The mill under construction is planned to have a capacity of at least 8000 tons per day.

The Climo Copper Company will operate in New Mexico, and is expected to commence production early this year. Its developed tonnage is 19,000,000 tons of 2·59 per cent. ore, and the concentrating plant is designed to treat 3000 tons per day. The newest important copper prospect is the Inspiration, near Globe, Arizona. The ore is a disseminated deposit, about 180 feet thick. The tonnage, which has been proved, is 19,000,000 tons of 2 per cent. ore.

Production of Metals in the United States.—The production of metals in the United States is given as follows :†—

Aluminium (pounds)	12,000,000
Copper ,, ...	1,086,151,430
Ferro-manganese (long tons) . .	240,520
Gold (dollars)	96,055,214
Iron (long tons)	27,055,067
Lead (short tons)	401,524
Nickel (pounds)	29,359,544
Quicksilver (flasks)	21,500
Silver (Troy ounces)	56,438,695
Zinc (short tons)	278,380

* *Metallurgical and Chemical Engineering*, February 1911, vol. ix. p. 60.
† *Engineering and Mining Journal*, January 7, 1911, vol. xci. p. 1.

The nickel returns are for the first eleven months only. The mineral statistics include 2130 short tons of tungsten ore.

The following figures are given as the statistics of the world's production of gold and silver during 1910 :—

Gold (dollars)	468,815,067
Silver (ounces)	217,788,714

while the production of platinum in the United States was 500 ounces for the period under review.

The following figures are given relative to the production of copper for the whole of the North American Continent :—

	Pounds.
United States	1,086,151,430
Mexico	131,765,910
Canada	50,408,276
Cuba	7,779,986

A table is given showing that, expressed in metric tons, the United States production of copper in 1910 was 492,675 tons, out of a total of 863,638 tons for the whole world.

Statistics of British Columbia.—According to E. Jacobs * the mineral output in British Columbia during 1910 has been estimated as follows :—

	Ounces.	Value, Dollars.
Gold (placer)	24,100	482,000
,, (lode)	257,000	5,312,190
Total gold . .	281,100	5,794,190

	Ounces.	Value, Dollars.
Silver	2,500,000	1,282,500
	Pounds.	
Lead	37,000,000	1,480,000
Copper	39,000,000	4,972,500
Zinc	4,000,000	184,000
Total metalliferous		13,713,190

Value of the World's Production of Gold.—The value of the gold produced in the world during the year 1910 was £90,974,800, as compared with £90,884,400 in 1909.† Africa figured in these totals with £35,000,000 and £34,200,000 respectively, the United States with £19,211,040 and £19,934,600 respectively, Australasia with £13,000,400 and £14,201,400 respectively, and other countries with £23,763,360 and £22,548,320 respectively. The production of gold from sands or gravels has increased of late years.

World's Production of Tin.—The world's production of tin is approximately 100,000 tons per year, according to C. F. Thomas. ‡

* *Engineering and Mining Journal*, January 7, 1911, vol. xci. p. 79.
† *Engineering*, February 3, 1911, vol. xci. p. 142.
‡ *Journal of the Chemical, Metallurgical, and Mining Society of South Africa*, October 1910, vol. xi. p. 164.

The Straits Settlements, Bolivia, and Banka Billiton account for 85 per cent. of the total, whilst Australasia, Cornwall, and Africa produce 12 to 13 per cent. Bohemia and Saxony are working low-grade cassiterite ores, associated with wolfram and bismuth. In the province of Yunnan, Western China, there are several thousand Chinese working on low-grade ores, but the bulk of the production does not reach the coast. Alluvial workings are responsible for the chief source of production, but the proportion of mined cassiterite is rapidly increasing.

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SECTION III.

MEMORANDUM AND ARTICLES OF ASSOCIATION, AND LIST OF MEMBERS.

CONTENTS

The Companies (Consolidation) Act, 1908

𝔐emorandum of 𝔄ssociation

OF
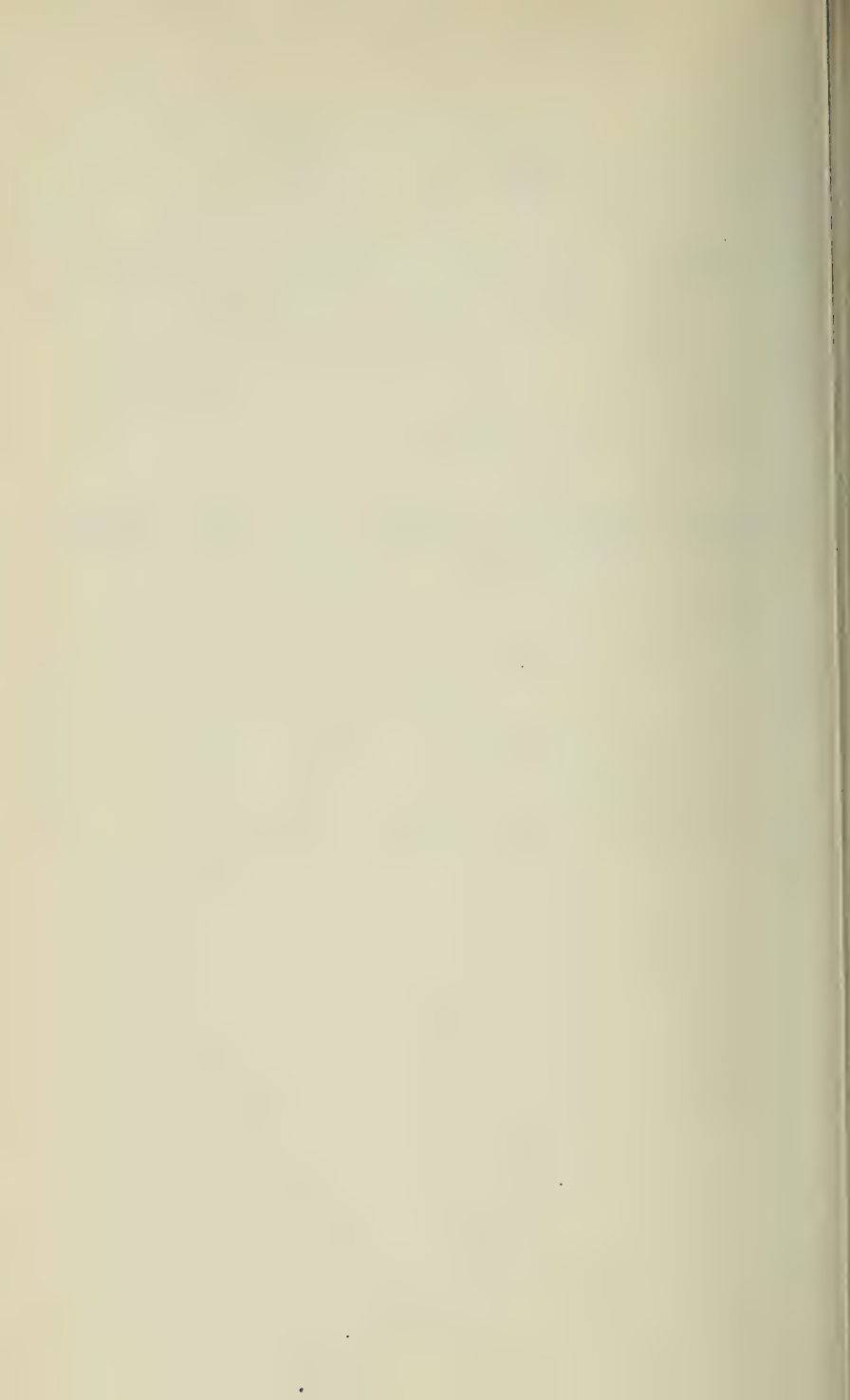
THE INSTITUTE OF METALS

1. The name of the Company is THE INSTITUTE OF METALS.

2. The Registered Office of the Association will be situate in England.

3. The objects for which the Association is established are :—

> (*a*) To take over the whole or any of the property and assets, which can be legally vested in the Association, and the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and, with a view thereto, to enter into and carry into effect, with or without modifications, the agreement which has already been engrossed and is expressed to be made between Gilbert Shaw Scott of the one part, and the Association of the other part, a copy whereof has, for the purpose of identification, been signed by three of the subscribers hereto.

> (*b*) To promote the science and practice of non-ferrous metallurgy in all its branches, and to assist the progress of inventions likely to be useful to the members of the Association and to the community at large.

(c) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures other than questions connected with wages, management of works, and trade regulations.

(d) To facilitate the exchange of ideas between members of the Association and between members of the Association and the community at large by holding meetings and by the publication of literature, and in particular by the publication of a Journal dealing wholly or in part with the objects of the Association.

(e) To establish Branches of the Association either in the United Kingdom or abroad to be affiliated to the Association upon such terms and conditions as may be deemed advisable, but so that all such Branches shall prohibit the distribution of their income and property by way of dividend or otherwise amongst their members to an extent at least as great as is imposed on the Association by virtue of Clause 4 hereof.

(f) To acquire by purchase, taking on lease or otherwise, lands and buildings and all other property real and personal which the Association, for the purposes thereof, may from time to time think proper to acquire and which may lawfully be held by them, and to re-sell, under-lease, or sub-let, surrender, turn to account, or dispose of such property or any part thereof, and to erect upon any such land any building for the purposes of the Association, and to alter or add to any building erected upon such land.

(g) To invest and deal with the moneys of the Association not immediately required in such manner as may from time to time be determined.

(*h*) To borrow or raise or secure the payment of money in such manner as the Association shall think fit, and in particular by Mortgage or Charge upon any of the property of the Association (both present and future), and to redeem and pay off any such securities.

(*i*) To undertake and execute any trusts, the undertaking whereof may seem desirable.

(*k*) To establish and support, or aid in the establishment and support of associations, institutions, funds, trusts, and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances and to make payments towards insurances, and to subscribe or guarantee money for charitable or benevolent objects or for any Exhibition or for any public, general, or useful object.

(*l*) To establish, form, and maintain a library and collection of metals, alloys, models, designs, and drawings, and other articles of interest in connection with the objects of the Association, or any of them.

(*m*) To give prizes or medals as rewards for research, for inventions of a specified character, or for improvements in the production or manufacture of non-ferrous metals and their alloys, and to expend money in researches and experiments, and in such other ways as may extend the knowledge of non-ferrous metals and their alloys.

(*n*) To do all things incidental or conducive to the attainment of the above objects or any of them.

Provided that the Association shall not support with its funds or endeavour to impose on or procure to be observed by its members any regulations which, if an object of the Association, would make it a Trade Union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Commissioners or Board of Education for England and Wales, the Association shall not sell, mortgage, charge, or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Council or Trustees of the Association shall be chargeable for such property as may come into their hands, and shall be answerable and accountable for their own acts, receipts, neglects, and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Council or as Trustees of the property of the Association have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exercisable by the Chancery Division, the Charity Commissioners, or the Board of Education over such Council or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control and authority as if the Association were not incorporated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association whenceso-ever derived shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever by way of profit, to the members of the Association. Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any member of the Association, in return for any services actually rendered to the Association, but so that no member of the Council or governing body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given to any

member of such Council or governing body except repayment of out of pocket expenses and interest at a rate not exceeding 5 per cent. per annum on money lent, or reasonable and proper rent for premises demised to the Association. Provided that this provision shall not apply to any payment to any railway, gas, electric lighting, water, cable, or telephone company of which a member of the Council or governing body may be a member, or any other company in which such member shall not hold more than one-hundredth part of the capital, and such member shall not be bound to account for any share of profits he may receive in respect of such payment.

5. The fourth paragraph of this Memorandum is a condition on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

6. The liability of the members is limited.

7. Every member of the Association undertakes to contribute to the assets of the Association in the event of the same being wound up during the time that he is a member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a member, and of the costs, charges, and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding one pound.

8. If upon the winding-up or dissolution of the Association there remains, after satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Association, but shall be given or transferred to some other Institution or Institutions not formed or carrying on business for profit having objects similar to the objects of the Association, to be determined by the members of the Association at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot

be given to the aforesaid provision, then to some charitable objects.

9. True accounts shall be kept of the sums of money received and expended by the Association, and the matter in respect of which such receipt and expenditure takes place, and of the property, credits, and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the members. Once at least in every year the accounts of the Association shall be examined and the correctness of the balance-sheet ascertained by one or more properly qualified auditor or auditors.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association.

Names, Addresses, and Descriptions of Subscribers

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, E.C., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th Day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,
Hastings House, Norfolk Street,
Strand, W.C.

The Companies (Consolidation) Act, 1908

Articles of Association

OF

THE INSTITUTE OF METALS

Section I.—CONSTITUTION

1. For the purposes of registration the number of members of the Association is to be taken to be 1000, but the Council may from time to time register an increase of members.

2. The subscribers to the Memorandum of Association and such other members as shall be admitted in accordance with these Articles, and none others, shall be members of the Association and shall be entered on the register of members accordingly.

3. Every person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the date of the incorporation of this Association, and who has not already become a member of this Association by virtue of having subscribed the Memorandum of Association thereof, shall be entitled to be admitted to membership of the Association upon writing his name in a book which has been provided for that purpose, or upon notifying in writing to the Association at its Registered Office his desire to become a member, and immediately upon the making of such entry or the receipt of such notice, shall be deemed to have been admitted and to have become a member of the Association and shall be placed upon the register of members accordingly, and thereupon any sums due and owing by such persons to the unincorporated Society shall immediately become due and payable by him to the Association.

4. Members of the Association shall be either **Honorary** Members, Fellows, Ordinary Members, or Student Members, and shall be respectively entitled to use the following abbreviated distinctive titles: Hon. Members, Hon. M.Inst.Met.; Fellows, F.Inst.Met.; Ordinary Members, M.Inst.Met.; and Students, S.Inst.Met.

Honorary Members.—It shall be within the province of the Council to elect not more than twelve honorary members, who shall be persons of distinction interested in or connected with the objects of the Association. Honorary Members shall not be eligible for election on the Council nor entitled to vote at meetings of the Association, and the provisions of Article 7 and Clause 7 of the Memorandum of Association shall not apply to such members.

Fellows shall be chosen by the Council, shall be limited in number to twelve, and shall be members of the Institute who have, in the opinion of the Council, rendered eminent service to the Association.

Ordinary Members shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be either (*a*) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys; or (*b*) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be either (*a*) Students of Metallurgy; or (*b*) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not. Student Members shall not be eligible for election on the Council nor entitled to vote at the meetings of the Association.

Section II.—ELECTION OF MEMBERS.

6. Save as hereinbefore provided, applications for membership shall be in writing in the form following marked "A.'

and such application must be signed by the applicant and not less than three members of the Association.

FORM A.

To the Secretary.

I, the undersigned,   , being of the required age and desirous of becoming a   Member of the Institute of Metals, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power ; and we, the undersigned, from our personal know-ledge, do hereby recommend him for election.

Name in full...

Address..

Business or Profession.......................................

Qualifications...

Signature..

Dated this   day of   , 19   .

.... ⎫ Signatures
.... ⎬ of three
.... ⎭ Members.

7. Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to

him of his election, as provided in the next clause hereof, his election shall be void.

8. Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form following marked " B."

FORM B.

Sir,—I beg to inform you that on the   you were elected a   Member of the Institute of Metals, subject to the payment by you of an entrance fee of £   , and of your first annual subscription of £   .   These must be paid to me on or before the   day of   19 , otherwise your election will become void.

I am, Sir, your obedient Servant,

....Secretary.

9. In the case of non-election, no mention thereof shall be made in the minutes.

Section III.—COUNCIL AND MODE OF ELECTION

10. The affairs of the Association shall be managed and conducted by a Council, which shall consist of a President, Past-Presidents, six Vice-Presidents, fifteen Members of Council, an Hon. Secretary or Hon. Secretaries, and an Hon. Treasurer. All members who have filled the office of President shall be, so long as they remain members of the Association, *ex officio* additional members of the Council under the title of Past-Presidents. The first members of the Council shall be the following:—President, Sir Gerard Muntz, Bart.; Vice-Presidents, Prof. H. C. H. Carpenter, Prof. W. Gowland, Prof. A. K. Huntington, Engineer Vice-Admiral H. J. Oram, Sir Henry A. Wiggin, Bart. Ordinary Members of Council, T. A. Bayliss, G. A. Boeddicker, Clive Cookson, J. Corfield, R. Kaye Gray, Summers Hunter, Dr. R. S. Hutton, E. Mills, J. T. Milton, G. H. Nisbett, E. Ristori, A. E. Seaton, Cecil H. Wilson, Prof. T. Turner (Hon. Treasurer), W. H. Johnson (Hon. Secretary).

11. Clauses 87, 89, 91, 92, 93, and 94 of the Table A in the First Schedule of the Companies (Consolidation) Act, 1908, shall apply to and form part of the Regulations of the Association, with the substitution of " Members of the Council " for " Directors " wherever in such clauses occurring.

12. The quorum for the transaction of business by the Council may be fixed by the Council, but shall not be less than five.

13. The first business of the Association shall be to acquire the property and assets, and to undertake the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and for the purpose of so doing the Council shall forthwith take into consideration, and, if approved, adopt on behalf of the Association, the Agreement referred to in Clause 3 (*a*) of the Memorandum of Association.

14. The President shall be elected annually, and shall be eligible for re-election at the end of the first year, but shall not be eligible for re-election again until after an interval of at least two years.

15. Two Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election. The members of the Council to retire in every year shall be those who have been longest in office since their last election, but as between persons who became members of the Council on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Association during the previous year, unless such non-attendance has been caused by special circumstances which shall have been duly notified to, and accepted by, the Council as sufficient explanation of absence.

16. At the Ordinary General Meeting preceding the Annual Meeting, the Council shall present a list of members nominated by them for election on the Council. Any ten members may also, at such Meeting, nominate a candidate other

than one of those nominated by the Council.   A list of candidates so nominated shall be forwarded to each member of the Association, and must be returned by him to be received by the Secretary not later than seven days preceding the Annual Meeting.

17. A member may erase any name or names from the list so forwarded, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated.   The lists which do not accord with these directions shall be rejected by the Scrutineers.   The votes recorded for any member as President, shall, if he be not elected as such, count for him as Vice-President, and, if not elected as Vice-President, shall count for him as ordinary member of the Council.   And the votes recorded for any member as Vice-President shall, if he be not elected as such, count for him as ordinary member of the Council.

18. The Council shall have power to appoint a member to fill up any vacancy that may occur in the Council during their year of office, but any person so appointed shall hold office only until the next following Ordinary General Meeting, and shall then be eligible for re-election.

Section IV.—DUTIES OF OFFICERS

19. The President shall be Chairman at all Meetings at which he shall be present, and in his absence one of the Vice-Presidents, to be elected, in case there shall be more than one present, by the Meeting.   In the absence of a Vice-President, the members shall elect a Chairman for that Meeting.

20. An account shall be opened in the name of the Association with a Bank approved by the Council, into which all moneys belonging to or received by the Association shall be paid.   All cheques on such account shall be signed by a member of the Council and countersigned by the Honorary

Treasurer. No account shall be paid before it has been certified as correct by the Council.

21. The Hon. Secretary or Secretaries shall be elected or appointed by the Council. He or they shall attend all Meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other moveable property of the Association, and shall perform such other duties as may be prescribed by the Council from time to time. In particular, he or they shall be responsible for editing the *Journal of the Institute of Metals.*

The Council shall have power to appoint a paid Secretary or Secretaries, and to delegate to him or them all or any of the duties of the Hon. Secretary or Secretaries.

Section V.—GENERAL MEETINGS

22. The First General Meeting shall be held at such time, not being more than three months after the incorporation of the Association, and at such place as the Association may determine. Subsequent there shall be at least two General Meetings in each calendar year, one of which shall be held in London during the first three months of the calendar year, and the other at such time after the said Meeting to be held in London and in such locality as the Council may direct. The Meeting in London shall be the Annual General Meeting.

The quorum for a General Meeting shall be 10 members personally present.

23. The Council may convene an Extraordinary General Meeting for any special purpose whenever they consider it to be necessary. The Council shall convene an Extraordinary General Meeting for a special purpose, upon a requisition to that effect, signed by not less than twenty members. The business of such a Meeting shall be confined to the special subjects named in the notice convening the same. No member whose subscription is in arrear shall be entitled to debate or to vote at any General Meeting.

In case of equality of voting at any Meeting the Chairman shall have an additional or casting vote.

24. Seven days' notice at the least (exclusive of the day on which the notice is served or deemed to be served, but inclusive of the day for which notice is given) specifying the place, the day, and the hour of Meeting, and, in case of special business, the general nature of that business, shall be given in manner hereinafter mentioned, or in such other manner, if any, as may be prescribed by the members of the Association in General Meeting, to such persons as are, under the regulations of the Association, entitled to receive such notices from the Association, but the non-receipt of the notice by any member shall not invalidate the meeting.

25. A notice may be given by the Association to any member, either personally or by sending it by post to him to his registered address, or (if he has no registered address in the United Kingdom) to the address, if any, within the United Kingdom supplied by him to the Association for the giving of notices to him.

Where a notice is sent by post, service of the notice shall be deemed to be effected by properly addressing, prepaying, and posting a letter containing the notice, and a certificate of the Secretary or other Officer of the Association that such notice was so posted shall be sufficient proof of service. A notice so posted shall be deemed to have been served the day following that upon which it was posted.

26. If a member has no registered address in the United Kingdom, and has not supplied to the Association an address within the United Kingdom for the giving of notices to him, a notice addressed to him and advertised in a newspaper circulating in the neighbourhood of the registered office of the Association shall be deemed to be duly given to him on the day on which the advertisement appears.

27. Notice of every General Meeting shall be given in some manner hereinbefore authorised to every member of the Association, except those members who (having no registered

address within the United Kingdom) have not supplied to
the Association an address within the United Kingdom for
the giving of notices to them. No other persons shall be
entitled to receive notices of General Meetings, but the Asso-
ciation may, but shall not be bound to give notice of General
Meetings to members not entitled thereto in such manner as
in the opinion of the Council may be practicable and con-
venient.

Section VI.—SUBSCRIPTIONS

28. The subscription of each ordinary member shall be two
guineas per annum, and of each student member one guinea
per annum. Ordinary members shall pay an entrance fee of
two guineas each, and students an entrance fee of one guinea
each. Provided that no entrance fee shall be required from
any person who was a member of the unincorporated Society
known as the Institute of Metals on the day preceding the
Incorporation of this Association, and who had paid an en-
trance fee to the said Society. No entrance fee or sub-
scription shall be payable in the case of Honorary members.

29. Subscriptions shall be payable in advance on July 1st
in each year, save in the case of Ordinary Members and
Student Members elected under Clauses 6 and 7 hereof,
whose entrance fee and annual subscription shall become
payable in accordance with the notification to them of their
election. Every subscription shall cover the period down to
the 30th of June next following, and no longer, and for this
purpose any subscription paid to the unincorporated Society
for the period of July 1st, 1909, to June 30th, 1910, by any
person who becomes a member of this Association shall go and
be in satisfaction of any payment due in respect of membership
of this Association up to the 30th of June 1910.

30. Subject to the provisions of Clause 7 hereof, any
member whose subscription shall be six months in arrear,
shall forfeit temporarily all the privileges of the Association.
Due notice in the Form following marked " C " shall be
given to such member, and if such subscription remains

unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

FORM C.

Sir,—I am directed to inform you that your subscription to the Institute of Metals, due   , and amounting to £   , is in arrear, and that if the same be not paid to me on or before the   day of   , 19   , your name will be removed from the Register of Members of the Association.

I am, Sir, your obedient Servant,

....Secretary.

31. The Council may, in their discretion, and upon such terms as they think fit (including the payment of all arrears), accede to any application for reinstatement by a person whose name has been removed from the Register under the last preceding Clause hereof, and the name of any person so reinstated shall be placed upon the Register of Members accordingly.

The Council, in their discretion, may remove from the Register the name of any member who shall, in the opinion of the Council, be undesirable or unfit to remain a member after first giving him a reasonable opportunity of being heard, and thereupon he shall cease to be a member of the Association.

Section VII.—AUDIT

32. The provisions of the Companies (Consolidation) Act 1908 as to Audit and Auditors shall apply to and be observed by the Association, the first General Meeting being treated as the Statutory Meeting, the Council being treated as the Directors, and the members being treated as the Shareholders mentioned in that Act.

Section VIII.—JOURNAL

33. The Journal of the Association may include one or more of the following :—

- (*a*) Communications made by members, students, or others.
- (*b*) Abstracts of papers appearing elsewhere.
- (*c*) Original papers appearing elsewhere.
- (*d*) Advertisements approved by the Council.

Every member shall be entitled to receive one copy of each issue of the Journal, delivered, post free, to his registered address.

Section IX.—COMMUNICATIONS

34. All communications shall be submitted to the Council, and those approved may be brought before the General Meetings. This approval by the Council shall not be taken as expressing an opinion on the statements made or the arguments used in such communications.

Section X.—PROPERTY OF THE ASSOCIATION

35. All communications so made shall be the property of the Association, and shall be published only in the Journal of the Association, or in such other manner as the Council may decide.

36. All books, drawings, communications, models, and the like shall be accessible to members of the Association, and the Council shall have power to deposit the same in such place or places as they may consider convenient for the members.

Section XI.—CONSULTING OFFICERS

37. The Council shall have power to appoint such consulting officers as may be thought desirable from time to time, and, subject to the provisions of Clause 4 of the Memorandum of Association, may vote them suitable remuneration.

Section XII.—INDEMNITY

38. Every member of Council, Secretary, or other officer or servant of the Association, shall be indemnified by the Association against, and it shall be the duty of the Council out of the funds of the Association to pay all costs, losses, and expenses which any such officer or servant may incur or become liable to by reason of any contract entered into or act or thing done by him as such officer or servant or in any way in the discharge of his duties, including travelling expenses.

Names, Addresses, and Descriptions of Subscribers

Gerard Albert Muntz, French Walls, Birmingham, Baronet.

Thomas Turner, The University of Birmingham, Professor of Metallurgy.

Alfred Kirby Huntington, The University of London, Professor of Metallurgy.

William H. Johnson, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

James Tayler Milton, Lloyd's Register, &c., Chief Engineer Surveyor.

Robert Kaye Gray, Abbey Wood, Kent, Civil Engineer.

Emmanuel Ristori, 54 Parliament Street, London, S.W., Civil Engineer.

Cecil Henry Wilson, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

William Henry White, 8 Victoria Street, Westminster. Naval Architect.

Henry John Oram, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th day of July 1910.

Witness to the above signatures—

Arthur E. Burton, Solicitor,

Hastings House, Norfolk Street,

Strand, W.C.

LIST OF MEMBERS

Elected
Member.

HONORARY MEMBERS

GLAZEBROOK, RICHARD TETLEY, C.B., M.A., D.Sc., F.R.S.,
Director, The National Physical Laboratory, Ted-
dington, Middlesex.

MATTHEY, GEORGE, F.R.S.,
Cheyne House, Chelsea Embankment, S.W.

NOBLE, Captain Sir ANDREW, Bart., K.C.B., F.R.S., 14
Pall Mall, S.W.

FELLOW

† *WHITE, Sir WILLIAM HENRY (Past President), K.C.B.,
Sc.D., D.Eng., LL.D., F.R.S.,
Cedarcroft, Putney Heath, S.W.*

ORDINARY MEMBERS

ADAMS, GEORGE,
Strathblane, Forest Glade, Leytonstone, Essex.

ADAMS, GEORGE NORTH,
Mars Iron Works, Wolverhampton.

ADAMSON, JOSEPH,
Oaklands, Hyde, Cheshire.

AINSWORTH, GEORGE,
The Hall, Consett, Durham.

1910 ALLAN, ANDREW, Jun.,
A. Allan & Son, 486 Greenwich Street, New
York, U.S.A.

ALLAN, JAMES McNEAL,
St. Peter's Works, Newcastle-on-Tyne.

ALLELY, WILLIAM SMITH,
3 Regent Street, Birmingham.

Elected Member.	

ALLEN, JOHN HILL,
    Spring Hill, Birmingham.

ALLEN, WILLIAM HENRY,
    Queen's Engineering Works, Bedford.

ALLMAN, WILLIAM,
    Cope, Allman & Co., Ltd., Icknield Square, Birmingham.

† ANDREW, JOHN HAROLD, M.Sc.,
    Victoria University, Manchester.

1910   ANDRI, ALFRED,
    Fabrique Nationale d'Armes de Guerre, Herstal-près-Liége, Belgium.

APPLETON, JOSEPH,
    Appleton & Howard, 12 Salisbury Street, St. Helens.

1911   APPLEYARD, ROLLO,
    79 St. Mary's Mansions, Paddington, W.

ARCHBUTT, LEONARD,
    4 Madeley Street, Derby.

1910   ASH, Engineer-Commander HAROLD EDWARD HAYDON, R.N.,
    H.M.S. " President," South West India Docks, E.

ASHOFF, WILHELM,
    Basse Selve, Altena, Westphalia, Germany.

ASTON, HENRY HOLLIS,
    Tennal House, Harborne, Birmingham.

BAILEY, GEORGE HERBERT, D.Sc., Ph.D.,
    Edenmor, Kinlochleven, Argyll, N.B.

BAIN, JAMES,
    The Cunard Engine Works, Huskisson Docks, Liverpool.

BAINBRIDGE, JOHN WILLIAM,
    2 Fen Court, Fenchurch Street, E.C.

BAKER, THOMAS, D.Sc., M.Met.,
    Westville, Doncaster Road, Rotherham.

BAMFORD, CHARLES CLIFFORD,
    Winfields Rolling Mills, Cambridge Street, Birmingham.

† BANNISTER, CHARLES OLDEN, Assoc.R.S.M.,
    60 West Side, Clapham Common, S.W.

1910   BARCLAY, ALEXANDER CLARK,
    Minas Sotiel Coronada, Prov. de Huelva, Spain.

† BARCLAY, WILLIAM ROBB,
    50 Upper Albert Road, Meersbrook, Sheffield.

BARKER, JOHN HENRY,
    Birmingham Metal and Munitions Company, Ltd., Adderley Park Mills, Birmingham.

BARNARD, ALFRED HENRY,
    H. B. Barnard & Sons, 59/60 Gracechurch St., E.C.
BARNARD, GEORGE,
    Callendar's Cable and Construction Company, Ltd.,
        Cambridge Street, Birmingham.
BARNES, ALFRED,
    Box 556, Pretoria, Transvaal.
BARR, Professor ARCHIBALD, D.Sc.,
    James Watt Engineering Laboratories, The Univer-
        sity, Glasgow.
BARWELL, CHARLES H.,
    Barwells Ltd., Pickford Street, Birmingham.

1910

BASSETT, WILLIAM H.,
    American Brass Co., Waterbury, Conn., U.S.A.
BATES, Major DARWIN,
    The Orchard, Huyton, Liverpool.
BATY, ERNEST JOCELYN, B.Sc.,
    Brush Electrical Engineering Co., Loughborough.
BAWDEN, FREDERICK,
    Garston Copper Works, Liverpool.
BAYLAY, WILLOUGHBY LAKE,
    Foremark, Dorridge, Warwickshire.
BAYLISS, THOMAS ABRAHAM,
    King's Norton Metal Co., Ltd., King's Norton, Bir-
        mingham.
BAYLISS, THOMAS RICHARD,
    Belmont, Northfield, Birmingham.
BEAN, G.,
    Allen Everitt & Sons, Ltd., Kingston Metal
        Works, Smethwick, Birmingham.
BEARE, Professor T. HUDSON, B.A., B.Sc.,
    Engineering Laboratories, The University, Edin-
        burgh.
BECKER, PITT,
    18/19 Fenchurch Street, E.C.
BEDFORD, CHARLES YVONE RILAND,
    H. H. Vivian & Co., Ltd., Icknield Port Road,
        Birmingham.
BEDSON, JOSEPH PHILLIPS,
    137 Lapwing Lane, Didsbury, Manchester.
BEER, LUDWIG,
    Beer, Sondheimer & Co., Frankfurt am Main,
        Germany.

1910 †

BEILBY, GEORGE THOMAS, LL.D., F.R.S.,
    11 University Gardens, Glasgow.
BELL, Sir HUGH, Bart.,
    Rounton Grange, Northallerton.

BELL, THOMAS,
 J. Brown & Co., Ltd., Clydebank, Dumbartonshire.

1911 BENEDICKS, Professor Dr. CARL ASEL FREDRIK,
 The University, Stockholm Va, Sweden.

† BENGOUGH, GUY D., M.A.,
 The University, Liverpool.

BENSEL, ARLINGTON,
 Driver Harris Wire Company, Harrison (Newark),
  New Jersey, U.S.A.

BENTON, ARTHUR,
 Benton Bros., Rodley Foundry, Sheffield.

BEVIS, HENRY,
 45 Basinghall Street, E.C.

1910 BEVIS, RESTAL RATSEY,
 Hamptoune, Vyner Road, Birkenhead.

BIBBY, JOHN HARTLEY,
 John Bibby & Co. (Garston), Ltd., Garston Copper
  Works, Liverpool.

BILES, Professor JOHN HARVARD, LL.D., D.Sc.,
 10 University Gardens, Glasgow.

BILL-GOZZARD, GEORGE,
 Stephenson Chambers, 39A New Street, Birmingham.

BILLINGTON, CHARLES,
 " Heimath," Longport, Staffordshire.

BIRCH, HARRY,
 J. Birch & Sons, Ltd., Upper Brook Street, Walsall.

BLAIKLEY, ARTHUR,
 181 Belsize Road, South Hampstead, N.W.

BLOOMER, FREDERICK JOHN,
 Penpont, Clydach, S.O., Glam.

BLOUNT, BERTRAM,
 76/78 York Street, Westminster, S.W.

BOEDDICKER, GUSTAV ADOLF,
 H. Wiggin & Co., Ltd., Wiggin Street Works, Bir-
  mingham.

BOLTON, THOMAS,
 T. Bolton & Sons, Ltd., 57 Bishopsgate, E.C.

BOOTH, CUTHBERT RAYNER,
 Jas. Booth & Co., Ltd., Sheepcote St., Birmingham.

BOW, WILLIAM,
 Bow, McLachlan & Co., Thistle Works, Paisley.

1911 BOWRAN, ROBERT,
 4 St. Nicholas' Buildings, Newcastle-on-Tyne.

BRABY, CYRUS,
 F. Braby & Co., Ltd., 110 Cannon Street, E.C.

BRAY, DAVID,
 Glenwood, Hardwick Road, Streetly, Birmingham.

Elected Member.	
	BRECKNELL, HENRY EDWIN FRANK,
	330 Fishponds Road, Eastville, Bristol.
	BRIDGES, FREDERICK WILLIAM,
	Ironmongers' Chronicle and The Hardwareman, 119
	Finsbury Pavement, E.C.
	BROADFOOT, JAMES,
	Lymhurst, South Brae Drive, Glasgow.
	BROADFOOT, WILLIAM RITCHIE,
	John Broadfoot & Sons, Ltd., Inchholm Works,
	James Street, Whiteinch, Glasgow.
	BROCKBANK, JOHN GEORGE,
	1 Cannon Street, Birmingham.
1910	BROOK, GEORGE BERNARD,
	Cravenhurst, Fulwood, Sheffield.
	BROOKS, JOHN FREDERICK,
	Engineering Dept., Municipal Technical School,
	Leicester.
	BROWN, CHARLES A. J.,
	"Glenroy," Gillott Road, Edgbaston, Birmingham.
1910	BROWN, JAMES,
	Scotts' Shipbuilding and Engineering Company,
	Ltd., Greenock.
	BROWN, ROBERT JOHN,
	W. Turner & Co., 75–79 Eyre Street, Sheffield.
	BROWN, WILLIAM,
	London Works, Renfrew.
1911	BROWNE, Sir BENJAMIN CHAPMAN, Kt.,
	R. W. Hawthorn, Leslie & Co., Ltd., St. Peter's
	Works, Newcastle-on-Tyne.
	BROWNSDON, HENRY WINDER, M.Sc., Ph.D.,
	81 Blenheim Road, Moseley, Birmingham.
	BUCHANAN, CHARLES,
	Lloyd's Register of British and Foreign Shipping,
	71 Fenchurch Street, E.C.
	BUCKWELL, GEORGE WILLIAM,
	Board of Trade Surveyors' Offices, Canning Place,
	Liverpool.
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